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NASA FBL / PBW Program NASA Boeing 757 HIRF Test Plan Low Power On-the-Ground Tests

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HIRF TEST PLAN
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1.0 Acknowledgments

This test plan was developed by the Lawrence Livermore National Laboratory (LLNL) in support of NASA's Fly-by-Light / Power-by-Wire program. The NASA Langley Research Center (LaRC) has responsibility for the HIRF effects and assessment methodology portions of the program. LLNL is tasked with developing modeling and analysis tools as well as with directing the aircraft tests to validate these tools. This test plan was written with input from Felix Pitts, K. Peter Zaepfel, Peter Padilla, and Charles Meissner of LaRC. Buddy Walton and Ly Dao of the USAF Phillips Laboratory and John Millard of United International Engineering, Inc. also provided valuable input.. This plan also borrows heavily from a test plan written by Howard LaValley of UIE.

2.0 Introduction

The NASA Fly-by-Light / Power-by-Wire (FBL/PBW) program was initiated to develop technology for a future generation of commercial transport aircraft. Studies have shown that an all-electric aircraft (PBW) could have substantial benefits in terms of weight and maintenance costs over today's aircraft that rely on hydraulic and pneumatic controls. However, one major concern regarding the all-electric aircraft is the potential for conducted and radiated electromagnetic susceptibility of its electronic controls. A way to potentially alleviate this problem (and save weight at the same time) is to route all control and signal information over optical fiber control links (FBL) that are inherently easier to harden against the electromagnetic environment (EME).

Since electro-optic devices and electronic digital computers will still be required, a major objective of the FBL/PBW program is to develop tools and techniques for assessing the survivability of the modern aircraft using such equipment in the electromagnetic environment. The EME includes both externally generated high intensity radiated fields (HIRF) and internally-generated radiated or conducted emissions. The ability to withstand internally-generated emissions is often referred to as electromagnetic compatibility (EMC).

The EME effects assessment tools and techniques developed under the program must ultimately be accepted by industry and the FAA regulatory body to be useful. Therefore, an important aspect of the program is that these tools and techniques must be validated to the satisfaction of this community. A series of aircraft tests are being planned for this purpose. Specifically, low power on-the-ground tests and fly-by tests will be conducted. This test plan describes, in detail, the on-the-ground tests which include those used for generating data for code validation as well as those which support the study of the stirred frequency technique. The test plan for the fly-by tests will be provided in a subsequent document.

3.0 Background

Full-threat tests of each make, model, and modification of each aircraft type would be far too expensive for the commercial aircraft community. Less expensive assessment methods usually rely on an EM stress-vs.-strength approach. In these methods, the EM stress that is applied to a component or subsystem is compared against the EM strength of the component or subsystem. The stress is measured as the current, voltage, power, or field that is received by or impressed upon an installed component or subsystem when the aircraft is exposed to the EME. The strength is the level of signal, expressed in the same units, the component or subsystem can withstand without upset or damage. There are several advantages to separating stress and strength. First, separating the stress estimate from the strength estimate allows the use of computer models, low power measurements, and/or similarity to estimate stress. These methods are much less expensive since they do not require the entire aircraft to be tested at full power. The strength can be measured with direct injection or radiation tests that involve only individual components or subsystems. Such tests inherently require less power and space to test than would full aircraft tests. This separation would allow the avionics manufacturers to test their boxes (strength tests) and the airframe manufacturers to test or analyze their airframes (stress tests) separately at reduced cost.

4.0 Test Program Objectives

The primary thrust of this aircraft test program is to develop a library or database of experimental results to be used in the evaluation of modeling codes. A second objective is to support the development of other assessment techniques such as mode-stirred chamber measurements. To support these objectives, it is also necessary to quantify measurement errors and to perform sensitivity studies to allow an estimation of the degree of agreement between measurement and model results that can reasonably be expected.

The data library will necessarily be limited in size and scope by cost and time constraints but will nonetheless provide a reasonable database for validation exercises involving computer codes that can be used for EME modeling activities. Here, the term validation is used to denote the determination whether a particular code is capable of producing accurate results for specific modeling tests in which it has been applied. Clearly, this will "validate" the physics kernel of the code, its numerical algorithms, and its overall ability to provide the "right" answer. Of possibly equal importance, the data might help to establish the limits of applicability of a code, the validity of approximations and extensions which can enlarge its applicability, and the resources such as computer time and memory required to attain various levels of accuracy.

A primary focus in this test plan is the validation of FDTD modeling of coupling into the airframe using a code such as TSAR. It will be tested extensively in its "intended " range where approximations other than discretization are not required (up to a few hundred MHz) as well as in the range where approximations and special algorithms will be required to estimate stress. While a description of the approximations used to extend the domain of applicability of the code is beyond the scope of this plan, adequate attention has been paid to collecting appropriate data to allow for its use in future validation activities.

In many cases deterministic models are insufficient to predict the stress within an airframe. Statistical approaches to this problem are being considered at several institutions, and theoretical and experimental foundations are being developed. LLNL has been studying statistical electromagnetics and experimental techniques based on mode stirred chambers. At frequencies where the airframe is many wavelengths, the aircraft interior can be modeled as a complex highly-overmoded cavity having random internal fields. It is hypothesized that the power at a randomly selected point has a statistical distribution that is independent of the details of the shape of the cavity. If this assertion is validated, it may be possible to use a similarity concept to characterize the stress applied to the line replaceable units (LRUs) within the aircraft. That is, once the parameters of the distribution are known, the LRUs environment is statistically determined. Airframe testing or analysis would be required only to determine the parameters of the distribution of coupling into the airframe. The statistical distribution and its parameters would not be expected to change with modifications of the avionics or other changes inside the complex airframe cavity. LRUs could be tested in a mode-stirred chamber that develops an internal EME having the same statistical distribution. Validating these concepts is another test objective.

It can be expected that a comparison of the results generated by measurements and computer analysis will not result in perfect agreement. The experimental and analytical or computational modeling approaches each have their own uncertainties and sources of error so that neither can be assumed to be the "standard" against which all other results must be evaluated. There are numerous sources of systematic and random measurement error and modeling error. The measurement sample size will be insufficient to eliminate the random errors, and some amount of systematic errors will always exist in the measurements. Also, there will always be some amount of modeling error in the model. The intent here is to maintain an appreciation of these errors and to perform a comparison in the light of the fact that measurement and analysis may provide equally valid results given the errors associated with each process. So, in order to quantify some of the larger of these errors, a series of tests will be made. These tests will allow us to establish reasonable error bounds about the measurement and computer model predictions for use during our comparisons.

5.0 Test Aircraft

The primary test object is the NASA/Eastern (Boeing) 757-200. The onboard certificate identifies the aircraft as a Boeing 757-225, Serial Number 22191 with the 225 denoting the specific configuration requested by the original sole owner (Eastern Airlines). In the following, this aircraft is referred to as the B-757, NASA B-757, NASA 757, etc., for convenience.

6.0 Program Test Sequence

Aircraft flight tests are required to convince the community of the validity of effects assessment techniques for in-flight aircraft. However, such tests are difficult and expensive. Orientation and position parameters and incident field values are difficult to control or measure accurately in such a test. A series of on-the-ground tests to validate both modeling and mode-stirred measurement techniques under well-controlled conditions will precede the flight tests to provide data under better controlled conditions and to reduce the risks associated with the flight tests.

This test sequence is not being planned to certify the safety of an aircraft. Rather, it is being planned to validate tools and techniques for assessment. Hence, the test plan will have a somewhat different emphasis than a certification test would have. Here, it will not be necessary to measure or predict EM effects on each critical subsystem nor is it necessary to measure coupling into every section of the aircraft that contains critical equipment. A few representative subsystems in a few aircraft sections will suffice.

In the next section of this test plan, we concentrate on the first validation step, the low level on-the-ground measurements. The fly-by tests will be the subject of another test plan. Suffice it to say, the fly-by tests will include measurements associated with radiation from a UHF radar at Wallops Island, an antenna driven by a VHF source, and a VOA station in Greenville, NC. The on-the-ground tests have elements which are in preparation for the fly-by tests.

7.0 Low-Power On-the-Ground Tests

The low-power on-the-ground tests encompass a series of tests which are meant to achieve a set of objectives defined in Sect 7.1. The tests have been arranged to enable execution of the tests in priority order and the rationale will become clear during the course of this plan. An attempt was made to construct a plan paying due attention to the limited aircraft availability time, the need for maximizing data acquisition time, the requirements for system dry-runs, and the existence of priority in the test series. In light of such considerations, the following represents a test plan satisfying significant constraints yet striving for maximum value. It has been constructed using reasonably conservative time estimates, some slack time, and a prioritization that permits inclusion and exclusion of tests as time permits.

7.1 On-the-Ground Test Objectives

There are four objectives and four test series for the on-the-ground tests. The first test series will meet the first objective which is to generate data to be used directly for coupling code validation. For this objective, discrepancies and uncertainties between measurement and model must be minimized. These tests will use dipole antennas, so the antenna can be included in the model. This eliminates the uncertainty in the exact form of the wave entering the model problem space. The second test series will meet the second test objective for the on-the-ground tests which is to exercise the equipment that will be used for the fly-by tests. For these tests, the test signals should match those planned for the fly-by tests. Thus, rather than stepped CW measurements, these tests will be conducted with fixed-frequency CW or pulsed waveforms. The exact polarizations and orientations are not required. Only test points planned for the fly-by tests need be examined. The third test series will meet the third objective for the on-the-ground tests which is to prepare for the fly-by tests, as well as to provide more data for validation of the codes (objective one). We wish to know the coupling into the airframe so that any high-Q coupling resonances near the fly-by frequencies can be taken into account as well as the sensitivity of coupling to uncertainties in aspect angle or the position of interior objects. The fourth test series will involve a continuing study of stirred frequency techniques.

7.2 On-the-Ground Test Facility

These tests will be conducted at the US Air Force Phillips Laboratory (PL) Large Electromagnetic System-Level Illuminator (LESLI) test facility. The LESLI facility is operated and maintained by the PL/WSM. This facility consists of a concrete pad, a two-wire rhombic antenna, and an instrumentation trailer. Time has been allocated for assembly and checkout of the data acquisition system and for a dry-run of the complete experimental system.

In the preparation of this test plan, an attempt has been made to minimize time-consuming aircraft operations such as repositioning of the aircraft on the pad. For example, as presently configured, this plan requires initial placement of the NASA B-757 at nose-on incidence in the LESLI, i.e., an orientation of the aircraft with its axis parallel to the LESLI axis. Following the tests in this orientation, tests will be executed at 10^{o} and at angles less than 10^{o}, if called for, and finally at broadside (90^{o} from nose-on).

The standard LESLI facility instrumentation will be used. This instrumentation is referred to as the CWDAS. The second test series will employ the LESLI rhombic antenna. PL will supply CW RF amplifiers which are part of the normal LESLI instrumentation while LLNL will supply a source capable of low power pulsed operation such as the HP 8360. The third test series will employ the LESLI rhombic antenna and its standard transmitters and instrumentation.

7.3 On-the-Ground Test Organizations and Responsibilities

7.3.1 Test Organization

The test support comes from many organizations. The NASA Langley Research Center (LaRC) is the funding organization for these tests. LaRC developed the on-board instrumentation. The Lawrence Livermore National Laboratory has responsibility for test planning and managing test execution. The Air Force Phillips Laboratory (PL) is located at Kirtland Air Force Base (KAFB). Emergency services, e.g., hospital, ambulance, and fire protection, are provided by the 377th Air Base Wing (377 ABW), KAFB. The Advanced Weapons and Survivability Directorate (PL/WS) within the PL is responsible for the LESLI facility. United International Engineering, Inc. (UIE) is a PL support contractor. The roles of each of these organizations is detailed below.

7.3.1.1 <u>Air Force - 377th Air Base Wing - Emergency and Security Services</u>

Air Force - 377th Air Base Wing will provide as required:

- (a) hospital
- (b) ambulance
- (c) security
- (d) fire protection (a 150 lb power bottle aviation-type fire extinguisher on the pad satisfies NASA safety requirements in this regard)

7.3.1.2 <u>Lawrence Livermore National Laboratory : Experimenter</u>

LLNL is responsible for the following tasks:

- (a) Defining test points, test sequence, test priorities
- (b) Defining sensor types
- (c) Defining test orientations, configurations and test frequencies
- (d) Final data analysis
- (e) Analytical predictions to compare to test results
- (f) Final data preparation before introduction into a test data library
- (g) Provide calibration factors for field (D dot) and voltage sensors used in the tests
- (h) Provide pulsed RF source

7.3.1.3 <u>NASA Langley Research Center: Program Manager</u>

NASA has the following responsibilities:

- (a) Provide the aircraft
- (b) Provide required aircraft safety / quality control personnel to assure that the aircraft flight worthiness has not been compromised by the tests
- (c) Provide a qualified ground crew who can power up aircraft systems, tow the aircraft to the required positions (or who can direct the PL/UIE aircraft ground crew to do this), etc. A 1/2 day notice will be provided to PL/UIE when towing is required.
- (d) Provide on-board instrumentation responsive to experiment needs
- (e) Provide personnel, as required, for set-up/operation of on-board instrumentation
- (f) Provide calibration data for the installed coaxial cables and VHF antenna

7.3.1.4 <u>Air Force Phillips Laboratory/WSM: Test Facility</u>

PL/WSM, in conjunction with UIE, will provide the following:

- (a) Provide and configure the LESLI test facility with rhombic antenna and calibrated instrumentation
- (b) Provide an aircraft tug and driver to install the aircraft into the LESLI facility
- (c) Provide instrumentation personnel
- (d) Provide safety assurance personnel, as required
- (e) Provide data processing support for quick-look processed data during testing
- (f) Calibrate current probes (current probes will be provided by NASA)
- (g) Provide data Quality Control (QC) personnel to review the test data.

7.3.2 Functional Responsibilities

The functional organization is shown in Figure 7.3-1.

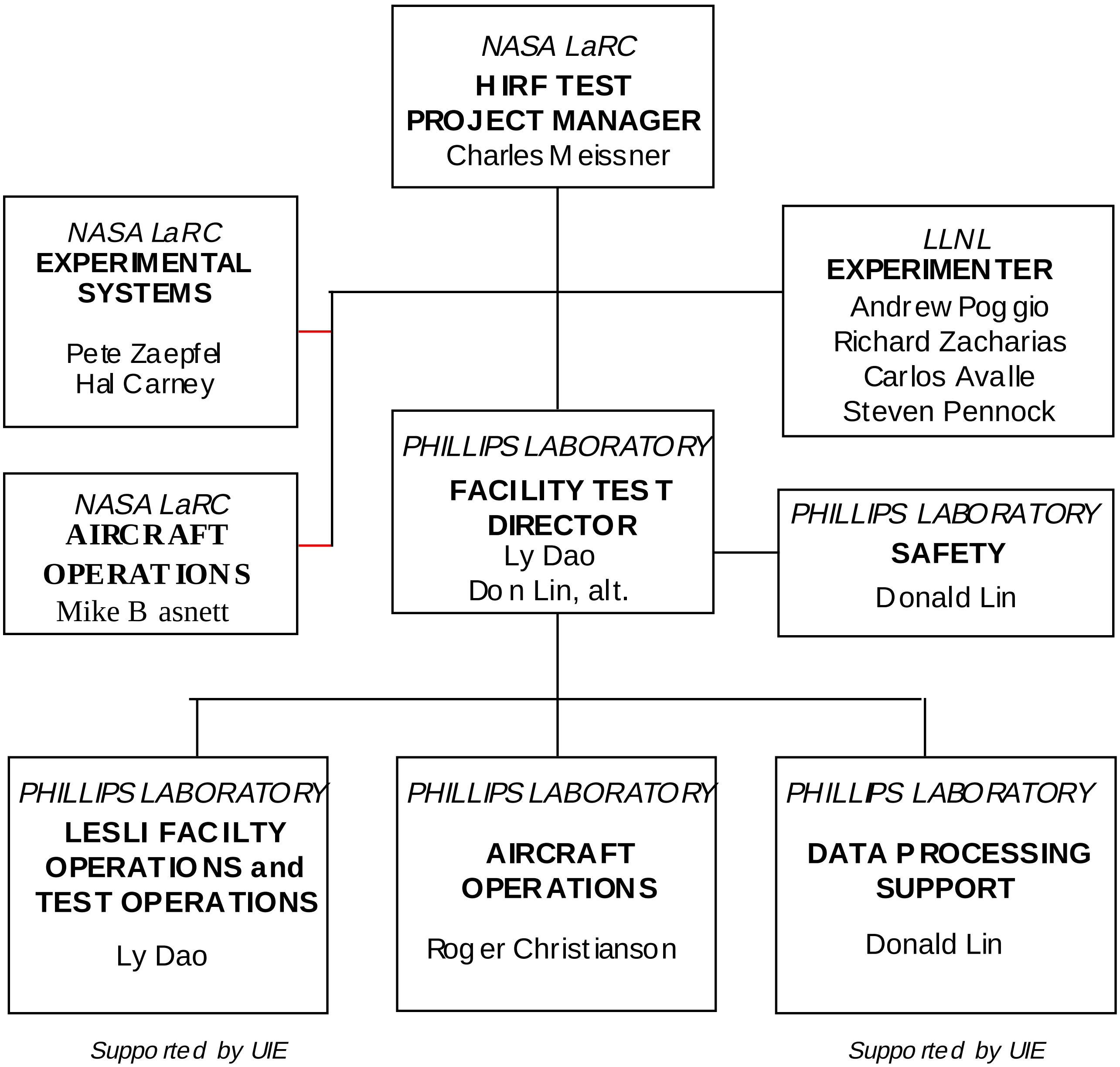


Figure 7.3-1. Functional organization.

7.3.2.1 <u>Experiment Test Director (LLNL)</u>

The Experiment Test Director will be Dr. Andrew Poggio. During testing, the LLNL Experiment Test Director, assisted by the PL Facility Test Director, will perform the test control function and will determine the experiment test sequence.

7.3.2.2 Facility Test Director (PL/WSM)

The PL Facility Test Director, Mr. Ly Dao, is responsible for the implementation of the approved test plan and test safety plan. The responsibility of Facility Director will encompass coordination of all activities required to acquire data, including aircraft/instrumentation readiness, data acquisition system readiness, and coordination of CW sweep initiation.

7.3.2.3 LESLI Facility Operations, Test Operations, and Support (PL/WSM supported by UIE)

Facility Operations is responsible for simulator facility support, including facility operations, data acquisition system integration and check-out, instrumentation characterization, data acquisition system operation, and data translation. Test Support is responsible for fiber optic instrumentation installation and quick-look data analysis.

7.3.2.4 Data Processing Support (PL/WSM supported by UIE)

CW data will be uploaded to the LESLI processing PC where it will be corrected for instrumentation effects. Accepted data will be written to standard tapes for delivery to LLNL and the data will be archived in the PCSLEET database.

7.3.2.5 Aircraft Operations (NASA LaRC)

NASA LaRC is responsible for movement, operations, and maintenance of the NASA aircraft. PL/UIE will support these activities during the tests. PL/UIE will also move the aircraft under NASA direction and provide other test support, as required.

7.3.2.6 Test Operations Working Group (All)

The Test Operations Working Group (TOWG), comprised of representatives from each organization, will meet daily during the test to insure test activity integration. Potential problems will be identified and an action item assigned for timely resolution.

7.4 Ground Plane

The concrete surface forming the pad in the LESLI facility will be used in an unaltered state as the ground surface. The aircraft will be positioned on this surface for the experiments. The LESLI is shown with and without the airplane in the scale drawings in Figures 7.4-1 through 7.4-4. The coordinate system for the ground plane is shown in Figure 7.4-1. The origin (0,0,0) is located at the rhombic feedpoint. This right-handed coordinate system, denoted **x, y, z,** is distinct from the coordinate system used for the interior of the aircraft that is fixed to the aircraft.

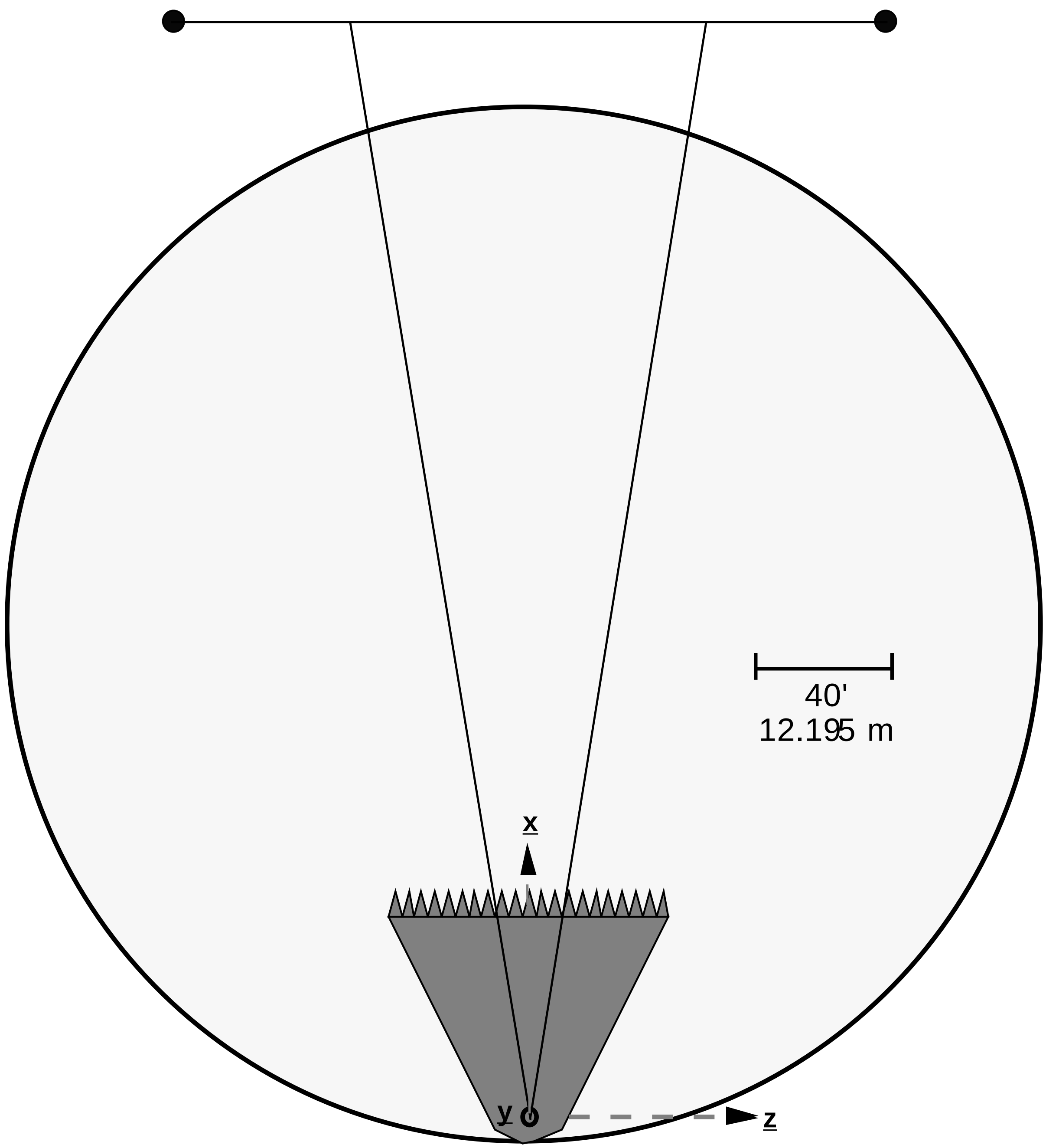


Figure 7.4-1. LESLI Facility with rhombic antenna
and ground plane coordinate system

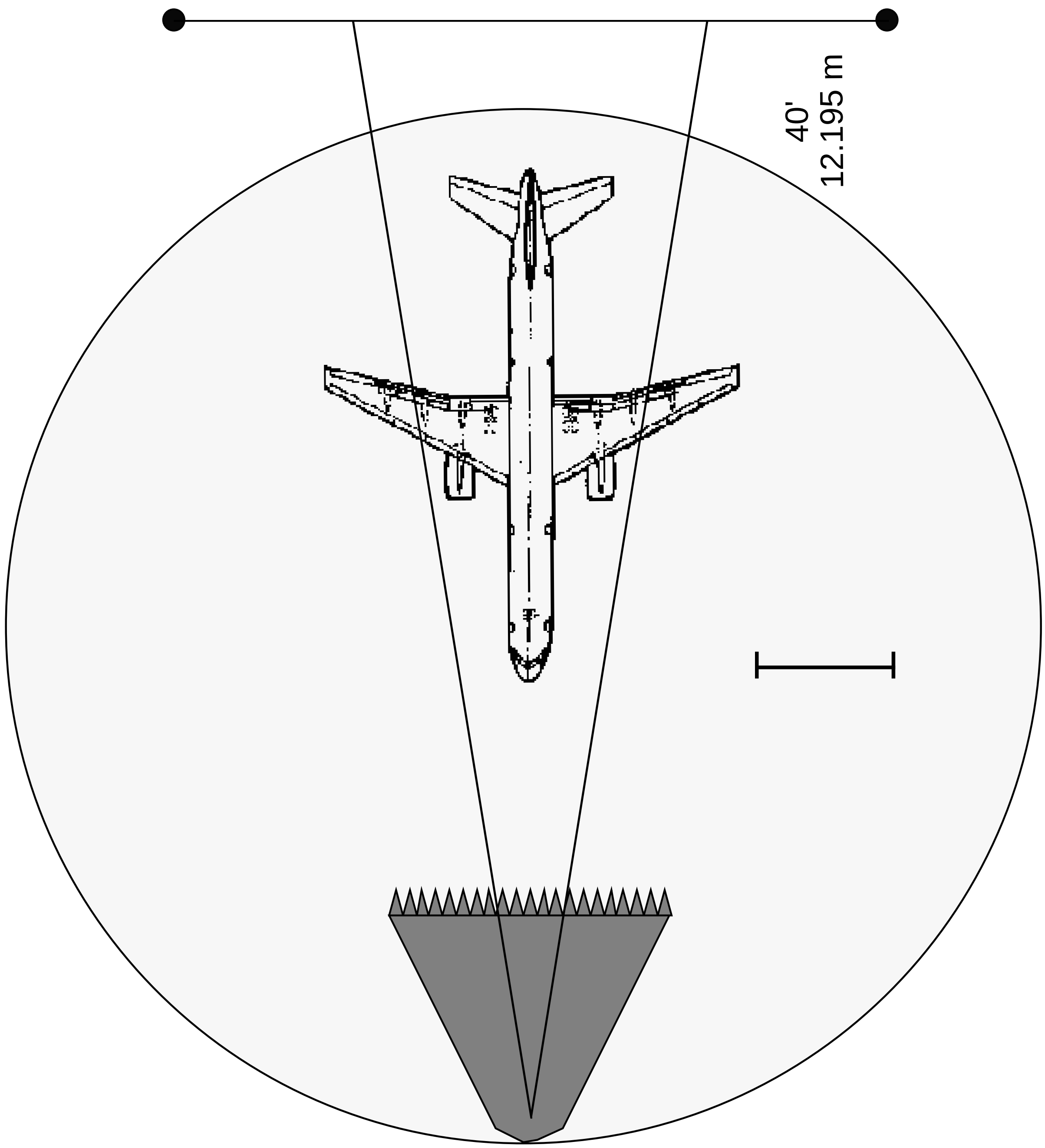


Figure 7.4-2. LESLI with B 757 nose-on incidence

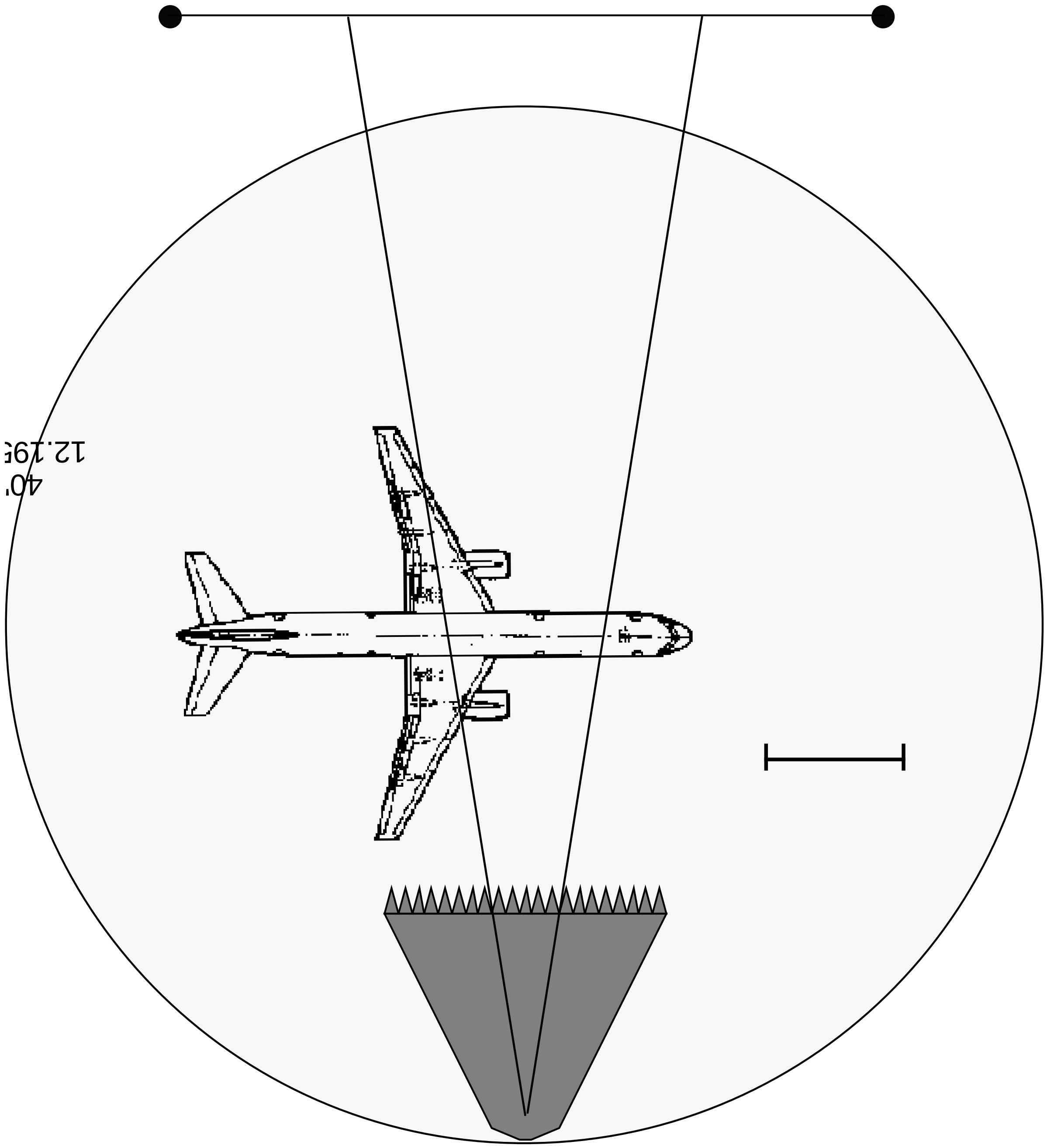


Figure 7.4-3 LESLI with B 757 broadside incidence

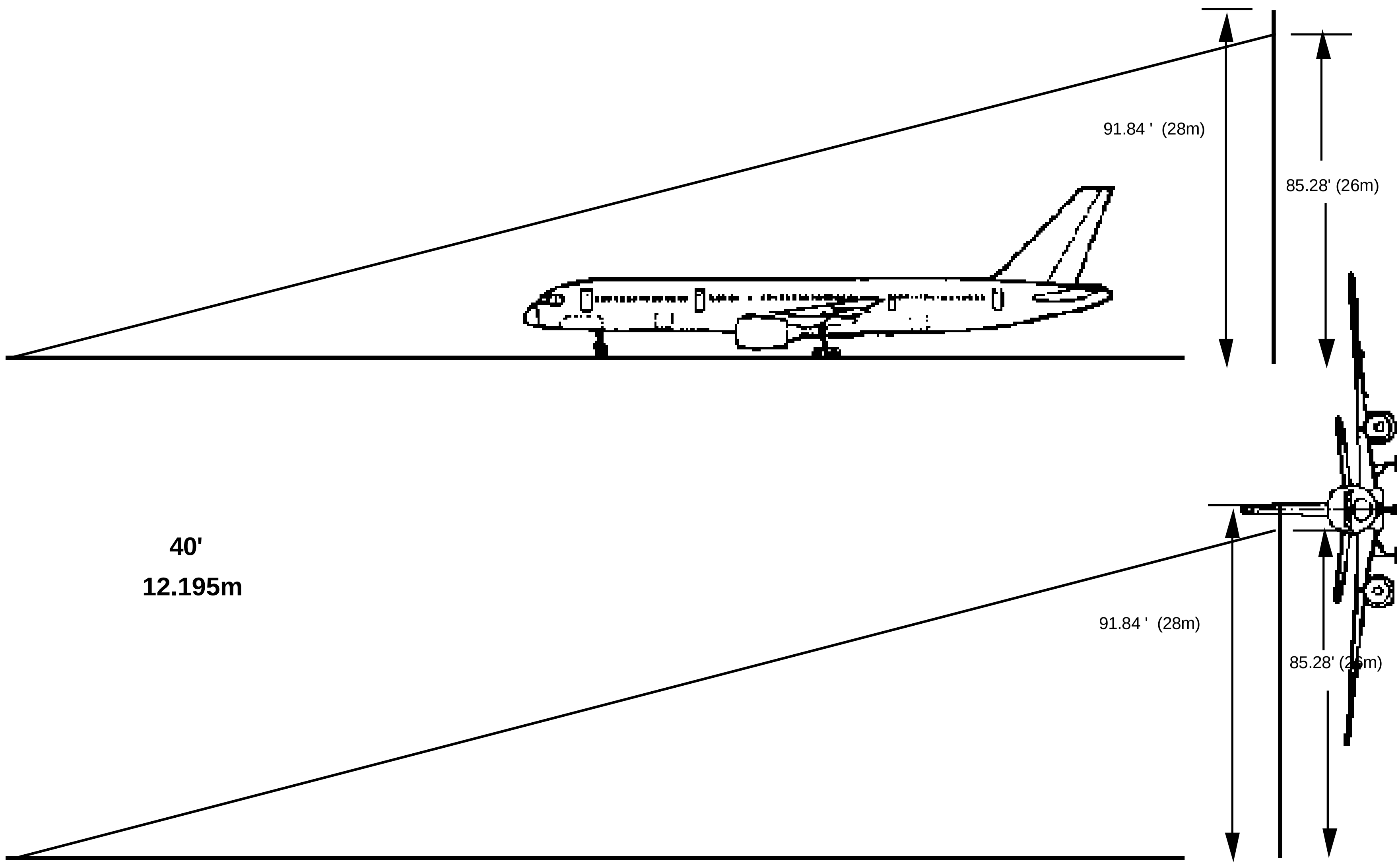


Figure 7.4-4 Side view of LESLI with B 757

7.5 Sensors

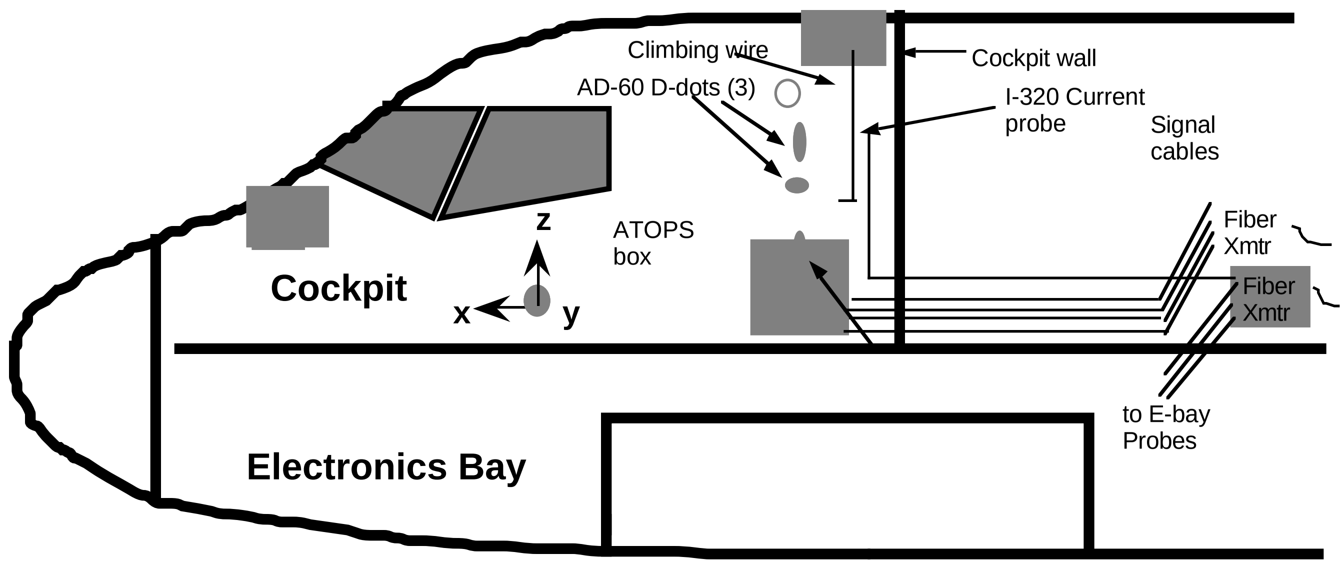
The sensors for the on-the-ground tests will be fitted into the aircraft prior to its arrival at Kirtland. Some of the sensors will be removed for the flight to Kirtland, and installed for the tests. The suite of 12 sensors will sample fields and cable currents and voltages in three aircraft bays: the cockpit, the electronics bay, and the cabin. Figures 7.5-1, 7.5-2, and 7.5-3 show sensor locations.

There will be five sensors in the cockpit. All of these sensors will be mounted onto the same sensor box that will be fabricated by NASA LaRC. This box is also referred to as the ATOPS box. The box contains three orthogonal Prodyne AD-60 D-dot sensors and a wire that extends through the box on which a voltage measurement is made within the box. Thus there are four connectors on the box. In addition, a Prodyne I-320 current probe will be used on the bare wire just outside of the box.

The electronics bay will contain three sensors. A Prodyne AD-60 will be used to measure fields within the bay. A Prodyne I-320 current probe will be placed onto an existing aircraft line for the windshield heater within the bay. The third measurement in the electronics bay will be made on a Collins VHF-700 transceiver box. In the remainder of this plan, this unit will often be referred to as the RC-7 box or unit. The unit will have been previously modified to provide a probe to measure the voltage on an internal power line pin. The unit will be installed into an existing slot in the electronics rack in the electronics bay after the aircraft arrives at Kirtland. The box will thus be connected to the avionics bus for low RF power stepped frequency tests. The box will be installed after the aircraft is positioned for tests. The box will be removed for the on-board instrumentation tests where aircraft power would be applied and then reinstalled for later power-off tests. (See 7.8.1).

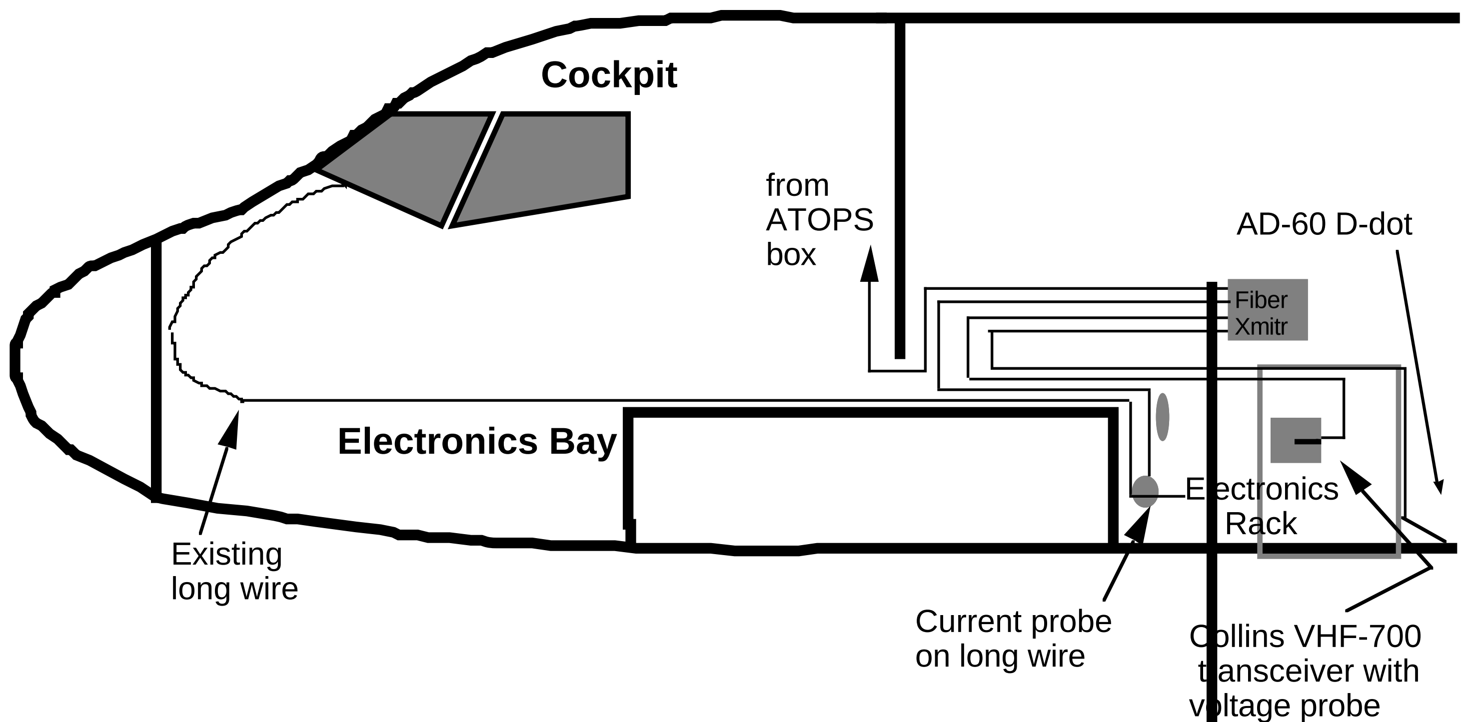
There will be four sensors in the cabin area. One of these will be an AD-60 D-dot mounted on top of the EME instrumentation rack. The second sensor will be a long-wire mounted along the ceiling of the cabin. This long wire will allow the measurement of small-signal low-frequency coupling. The long wire will terminate into a 50 ohm cable across which voltage will be measured. A current sensor will also be installed onto the semi-rigid coaxial cable feeding the long wire to sense external shield current. The fourth cabin sensor will be the VHF-L (left) antenna which is part of the normal complement of external antennas for the NASA aircraft . This antenna will provide a measurement of the external field (perturbed by the aircraft) and will provide a strong signal to be used as a trigger for the fly-by tests.

LaRC will provide cables from each sensor that will mate to either the on-board instrumentation or will mate to fiber optic transmitters for the swept frequency measurements.



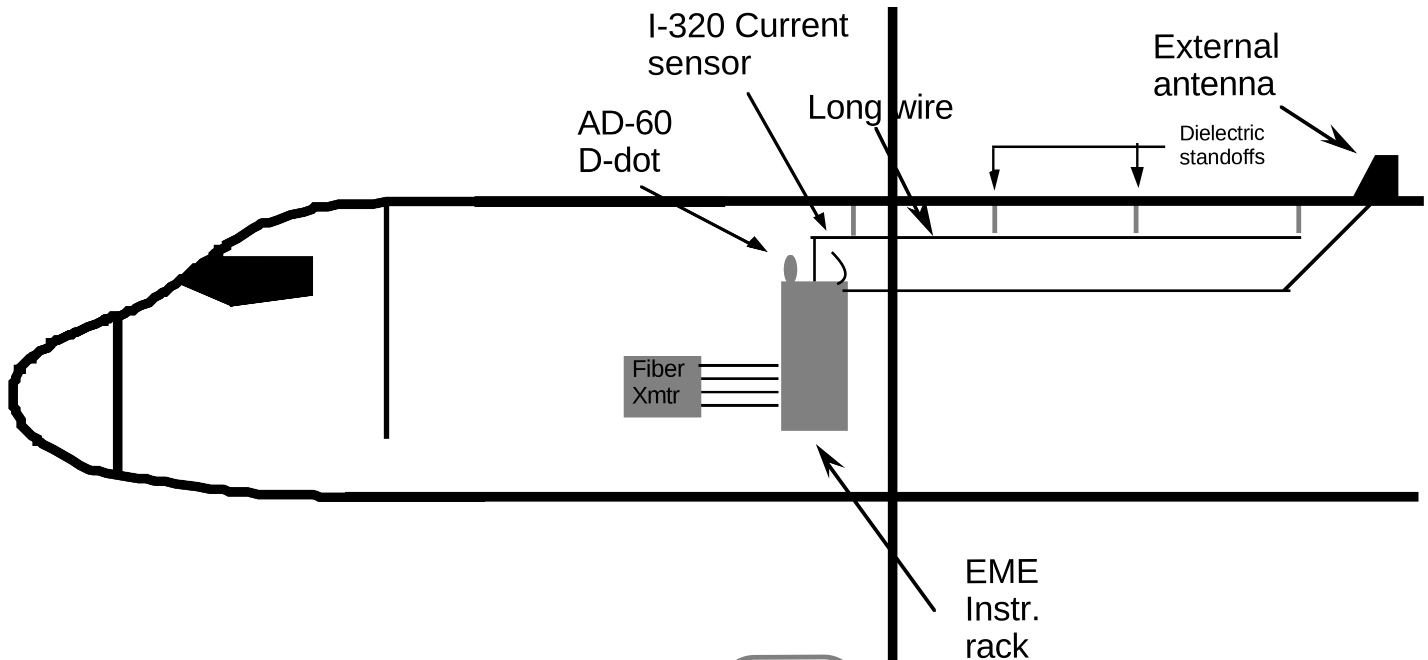
Ch.#	Probe	Parameter	Location	Fly-by channel?
T1C1	AD-60	Ex Field	ATOPS box	N
T1C2	AD-60	Ey Field	ATOPS box	N
T1C3	AD-60	Ez Field	ATOPS box	Y
T1C4	I-320	Current	ATOPS box	N
T2C1	Wire	Voltage	ATOPS box	N

Figure 7.5-1. Cockpit sensors.



Ch. #	Probe	Parameter	Location	Fly-by channel?
T2C2	AD-60	E Field	Elect. bay	Y
T2C3	I-320	Current	Existing wire	Y
T2C4	50 ohm	Voltage	RC-7 Tcvr	N

Figure 7.5-2. Electronics bay sensors



Ch. #	Probe	Parameter	Location	Fly-by channel?
T3C1	Ext. Ant.	Ext. Field	Fuselage	Y
T3C2	AD-60	Field	Equip rack	Y
T3C3	Long Wire	Voltage	Ceiling	Y
T3C4	I-320	Current	Long wire	Y

7.6 Pretest Procedures

7.6.1 Characterization and Checkout

7.6.1.1 Probe Characterization. Characterizations of the field mapping probes and current probes will be performed by the PL LESLI Facility Operation and Support Group prior to the start of the test. Probe characterizations shall be performed following the Continuous Wave Data Acquisition System (CWDAS) User's Guide. Figures 7.6-1 and 7.6-2 show the configurations used for the cable/attenuator/splitter, and current probe characterization. Current probes and cables will be characterized over the allowable CW logarithmic sweep frequencies in the 300KHz to 1 GHz band as listed in the CWDAS User's Guide using Q's developed for the LESLI Field Map Testing. These data points will match those used for the rhombic antenna sweeps described in Section 7.9. For the narrowband sweeps using the dipole (described in Section 7.7) or narrowband rhombic sweeps, calibration data will be acquired in the same manner. Sensor characteristics will be provided by NASA/LLNL while calibration data for the cables installed aboard the aircraft will be provided by NASA.

7.6.1.2 Coaxial Instrumentation Cable Check-out. All external cables will be characterized using CWDAS by the Facility Support Group. Four sets of data characterizations will be done for each of the experiments described above. The data will be recorded in Toolkit format on PC-readable floppy disks and uploaded to the LESLI processing PC running MatLab. Cables will be visually inspected during the test. When acquired data are questionable, a cable characterization may be repeated as requested by the Test Director.

7.6.1.3 Link Characterization. Fiber optic data links will be characterized using CWDAS by Facility Support Group. The data will be uploaded to the LESLI processing PC running MatLab. The test setup used to characterize the fiber optic data links is shown in Figure 7.6-3. The links shall be characterized over a frequency range of 300 KHz through 1 GHz.

7.6.1.4 Dry Runs. A series of dry runs will be executed to provide assurance that all elements of the experiment system are functioning properly. The dry runs will involve use of all available RF sources and amps, all antenna (illuminator) systems, selected sensors, and the data acquisition system that includes the instrumentation, computer control, acquisition and display functions. In effect, these runs will be "full-up" except for the presence of the NASA aircraft. It will test both the systems and the operational procedures in effect during the tests.

7.6.1.5 FAA Compatibility Tests Prior to the arrival of the aircraft, compatibility tests will be conducted to assure that the tests involving new frequency and antenna configurations cause no interference with operation of the FAA control tower. These tests will include all stepped frequency dipole test configurations (see Section 7.7) and all fixed CW and pulsed CW configurations (see Section 7.8). Power levels expected during the test sequences will be used.

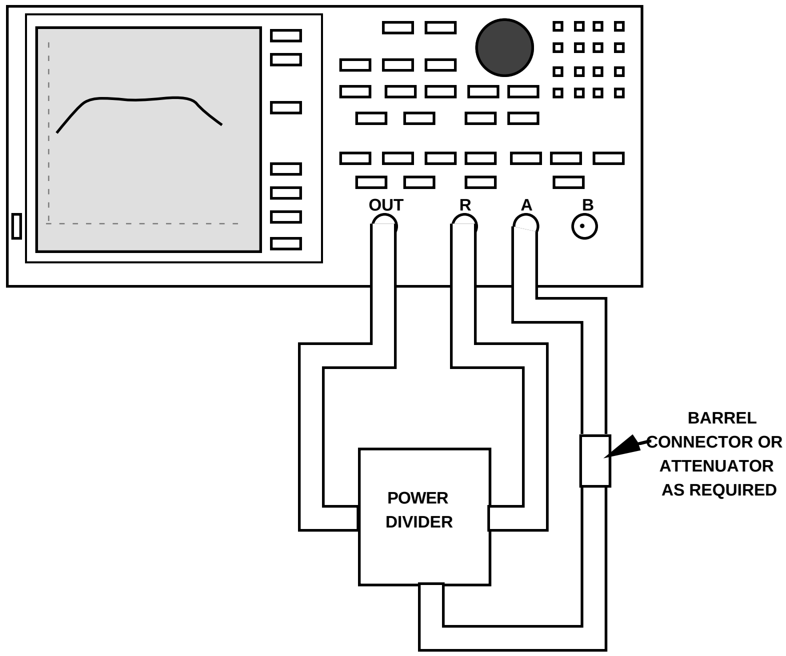


Figure 7.6-1. Cable / attenuator / splitter characterization test setup.

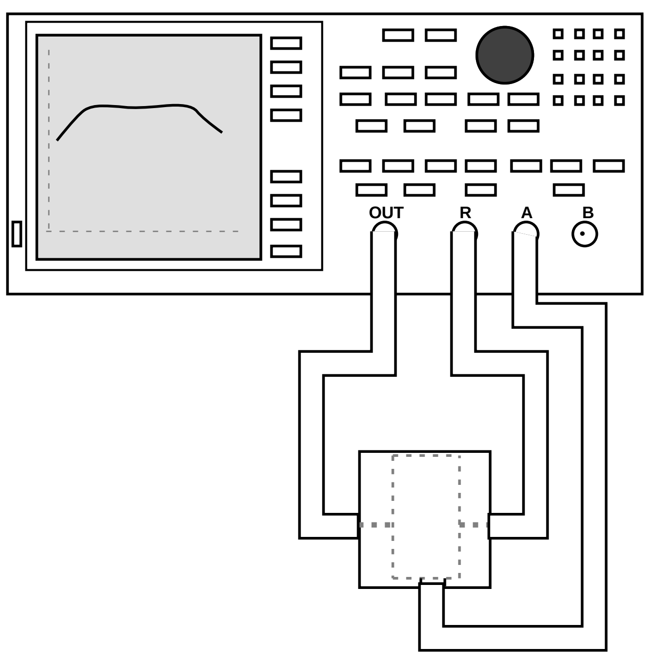


Figure 7.6-2. Probe characterization test setup.

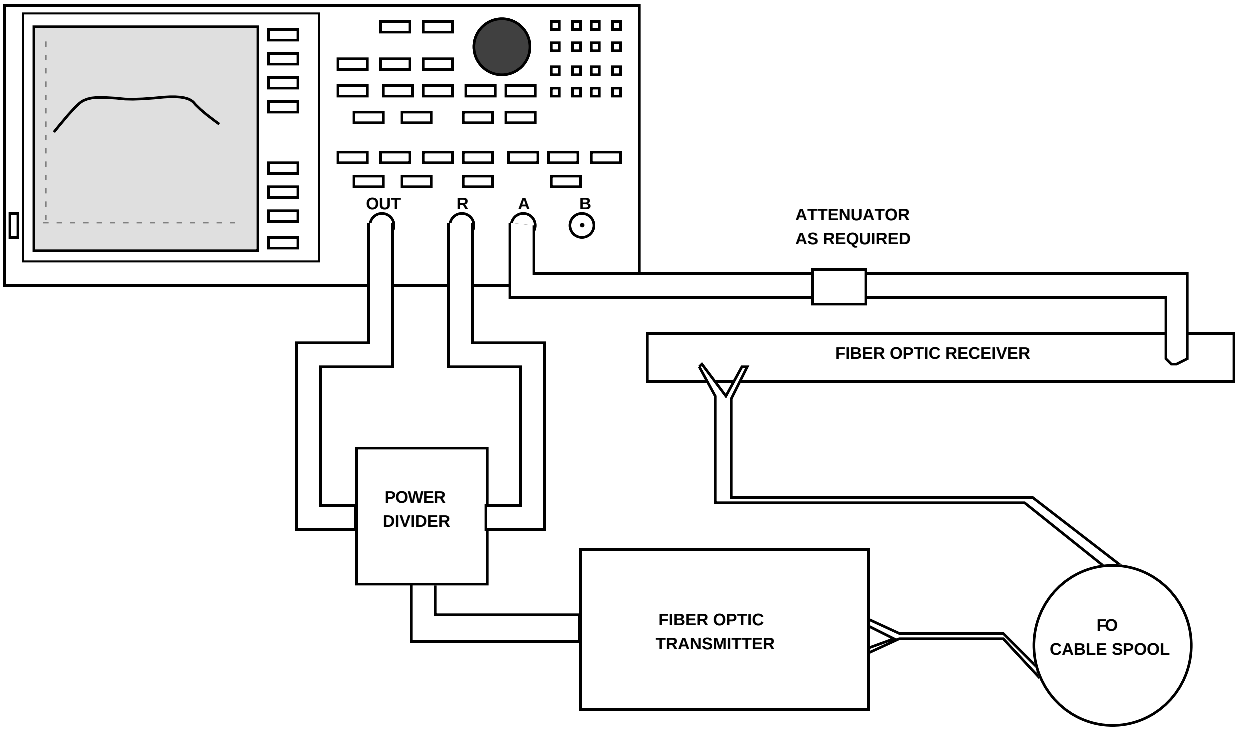


Figure 7.6-3. Fiber link characterization test setup.

7.6.2 Field Mapping

7.6.2.1 Rhombic Antenna

Prior to making swept CW measurements with the Rhombic antenna, field mapping measurements will be made to provide a baseline of the incident field wavefront. It is prohibitively expensive to make sufficient measurements to completely determine field components throughout the entire volume or over the closed surface of any computational volume for the numerical models which might be employed. (This is the primary reason for the dipole experiments described in Section 7.7.)

A model for the rhombic antenna exists that will relate the voltage incident to the antenna to the field at any point in space under the antenna. If this model were completely accurate and validated, no field mapping would be necessary. Since this is not the case, we must make measurements to validate it. However, we can use the model to greatly reduce the number of field map measurements required. Our plan is to make a few measurements to recalibrate the model, and then use the model to define the incident fields in the computer coupling models.

The field map locations are described in Table 7.6-1. Field measurements will be made in each of three orthogonal directions at each test point. B-field measurements will be made at each point and E- (or D-) field measurements will be made at select points. These are denoted E&H in the table. Measurements will be made over the entire 300 KHz to 1 GHz band. The frequency sample spacing will be adjusted to match that of the stepped CW measurements described in Section 7.9.

In Table 7.6-1, the coordinates are defined with the **x** axis along the center line of the rhombic illuminator, the **y** axis orthogonal to the ground plane in the vertical direction, and the **z** axis orthogonal to the y-z plane and parallel to the ground plane. The origin is at the feed point and the system is right-handed. This coordinate system is shown in Figure 7.4-1.

Table 7.6-1. Rhombic Field Map Locations.

x (meters)		y (meters)	z (meters)
40		1	0
40		3	0
40		3	2
40		3	8
40		3	15
40		5	-2
40	E&H	5	0
40		5	2
40	E&H	5	5
40		5	8
40	E&H	5	10
40		5	12
40		5	15
50		3	0
50		3	5

7.6.2.2 Dipole Antennas

Dipole antennas will also be used in certain tests. While these are to be included in the modeling volume and should, in principle, not require field mapping, it has been considered advisable to perform a limited mapping exercise. To this end, the dipole fields will be mapped as described in Table 7.6-2 with the field at each point measured for the three orthogonal directions. In some cases denoted by E&H, both the E- and H- field will be measured. The coordinate system for these maps is indicated in Figure 7.6-4. The frequencies in the table define the approximate center frequency of a range of frequencies that is defined in the test matrices for the dipole tests. These frequency ranges will be extended above and below the center frequencies by an amount that will allow the structure of the spectrum in that vicinity to be investigated. The range may be limited by self-protection devices in the amplifiers which protect against high VSWRs at the transmitter output.

H Pol and V Pol refer to horizontal and vertical polarization, respectively, for the dipoles. For convenience, both orientations are shown in Figure 7.6-4. The height of the dipole feed point in the mapping exercises is 3 meters except for vertical polarization near 25 MHz when it is 4 meters.

The coordinates in the table are relative to a point on the pad directly below the feed point of the dipoles. This point will be identical to that used during the dipole test sequence.

Original plans included use of a highly conducting plane composed of interlocked aircraft landing mats. Unavailability has required use of the concrete pad in an unaltered state. Hence, it will be necessary to characterize the pad from an electromagnetic standpoint. This will be performed after the NASA 757 test series is complete and will be the subject of another test plan.

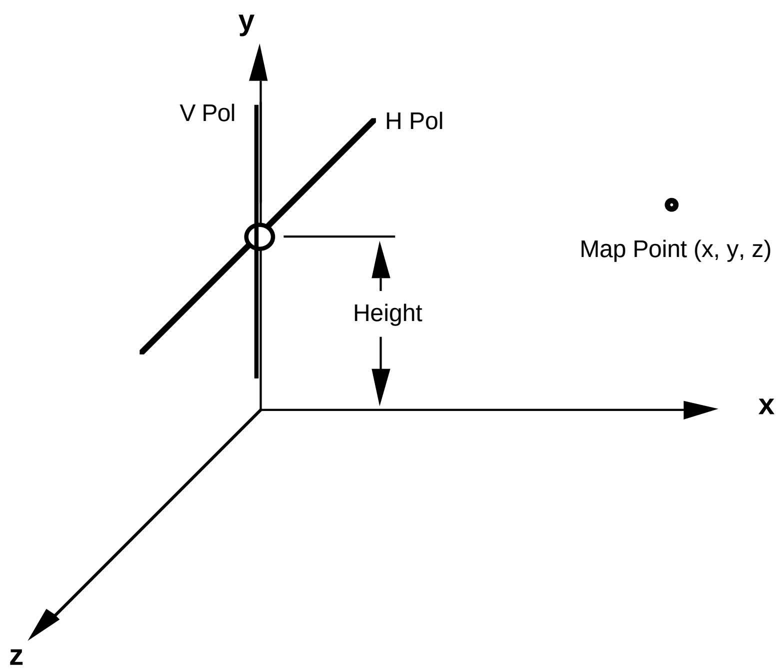


Figure 7.6-4 Dipole Field Mapping Coordinate System

Table 7.6-2. Dipole Field Map Locations.

freq(MHz)	pol	x (meters)	y (meters)	z (meters)	
25	V	2	4	0	E&H
25	V	8	4	0	
25	V	8	2	0	
25	H	2	3	0	E&H
25	H	8	3	0	
25	H	8	2	0	
172	V	2	3	0	E&H
172	V	8	3	0	
172	V	8	2	0	
172	H	2	3	0	E&H
172	H	8	3	0	
172	H	8	2	0	
430	V	2	3	0	E&H
430	V	8	3	0	
430	V	8	2	0	
430	H	2	3	0	E&H
430	H	8	3	0	
430	H	8	2	0	
25	H	8	3	6	
25	H	8	3	-6	
172	H	8	3	6	
172	H	8	3	-6	
430	H	8	3	6	
430	H	8	3	-6	

7.6.3 Aircraft Pretest Activities

Before the aircraft arrives at KAFB, NASA LaRC will have installed some test probes and will have marked them with identification tags. Once the aircraft is positioned for the first test series, additional probes (including the RC-7 unit) will be installed by LaRC personnel. Not all probes are used for all test series. The sensors will remain installed in the same position for all test series, with a few exceptions which are noted in the test matrix.

The NASA aircraft will arrive at Kirtland AFB on September 18, 1994. The following paragraphs detail the expected pre-test activities.

7.6.3.1 Initial Aircraft Positioning. The aircraft will be towed from the runway to the LESLI facility and positioned under the antenna. The aircraft will be positioned appropriate for a test using the LESLI antenna with the aircraft cockpit facing the incident wave. However, at this time the LESLI two wire antenna will have been removed. NASA LaRC will be responsible for moving and repositioning the aircraft with support from PL/UIE Aircraft Operations. LLNL will provide additional support for aircraft alignment. Facility Support will provide the required aircraft grounding equipment which will be installed during down times and after-hours only, not during the tests. The aircraft will remain in place through the dipole tests, unless otherwise directed by NASA LaRC.

7.7 Stepped CW Measurements: CWDAS with Dipole Antennas

7.7.1 Probe Installation

Two 300 KHz to 1 GHz Nanofast fiber optic data links will be employed for acquiring data from probes mounted in the aircraft.. Each link can support four inputs. Upon placement of fiber cables, the aircraft may be inspected by NASA and Aircraft Operations to ensure that all installations are done according to previously approved test modification packages and that the aircraft integrity has not been compromised.

7.7.2 Dipole Antennas

Dipole antennas will be used for these test series. The antennas will be simple thin-cylinder or thin-wire antennas mounted parallel to both the aircraft fuselage axis and ground for horizontal polarization or mounted perpendicular to the ground for vertical polarization. The geometrical arrangement is shown in Figure 7.7-1 with all coordinates in meters and the origin at the nose of the aircraft, as shown. The dipole source (its center) is located at (-4, 3, -5) for all frequencies except for the vertical polarization test near 25.85 MHz when the center is raised to (-4, 4, -5). A reference probe (B dot sensor) is used in the measurements and is located 3.5 meters from the dipole source for all frequencies except for the measurements near 25.85 MHz when the sensor is 5 meters from the dipole source. The coordinates are (-1.525, 3, -7.475) and (-0.465, 3, -8.535), respectively. Details for the emplacement are found in Figure 7.7-1.

These thin-wire dipole antennas are not expected to have ultra-wide bandwidths. Thus, separate antennas will be required for each of the three fly-by frequencies. These frequencies are set at 25.850 MHz, 172.0 MHz, and 430 MHz. The aircraft will be illuminated with both vertical and horizontal polarization using dipoles for both polarizations. The dipoles will be cut to half-wavelength resonance near each fly-by frequency. Stepped frequency measurements will be made over a band extending from 80% to 120% of each center frequency or as permitted by equipment

VSWR restrictions. The starting frequency, frequency step size, and number of data points to be taken for each test series is shown in Table 7.7-1.

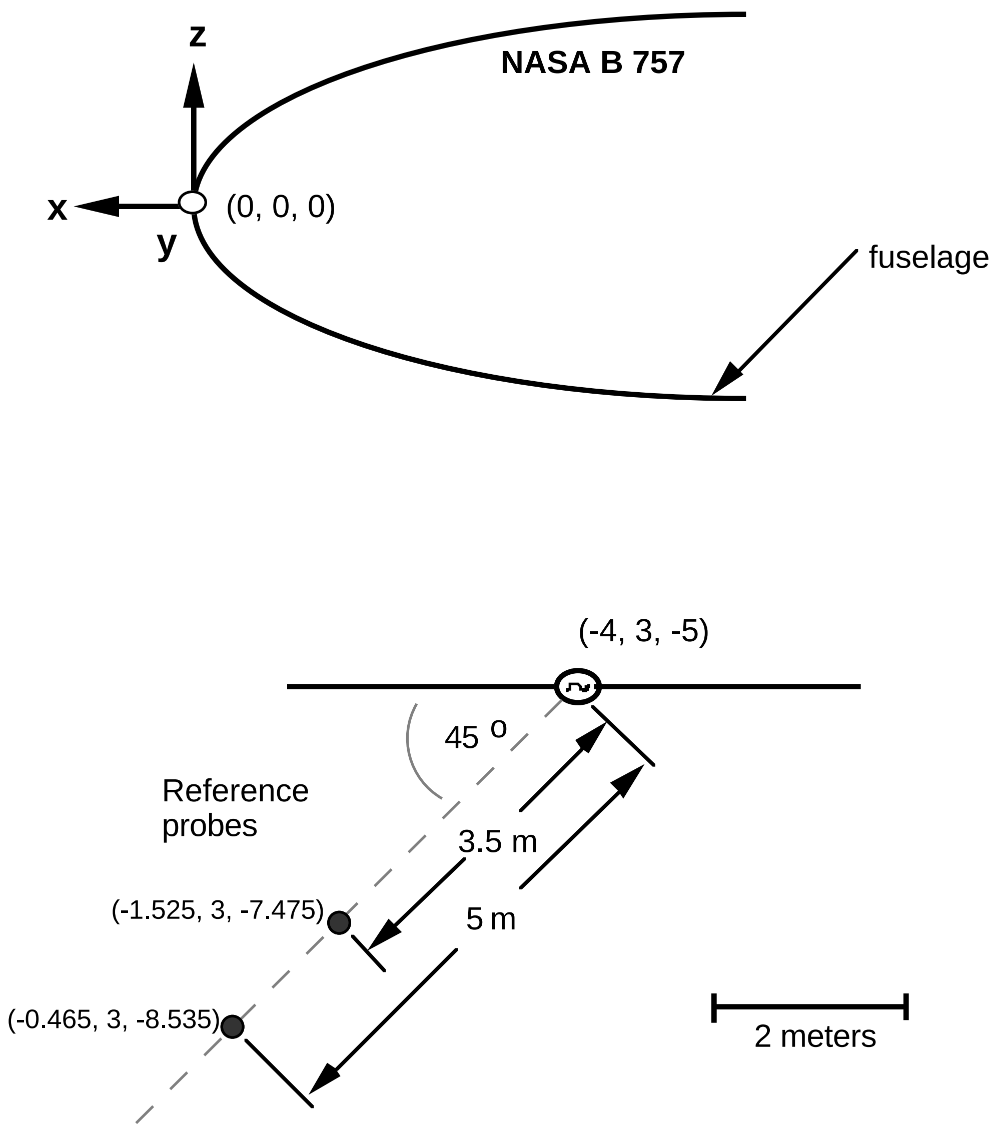


Figure 7.7-1. Dipole and reference probe locations for dipole tests

7.7.3 Dipole Test Operations

This section outlines the specific operations which will be employed for the dipole tests. A block diagram of the instrumentation used for the dipole tests is shown in Figure 7.7-2.

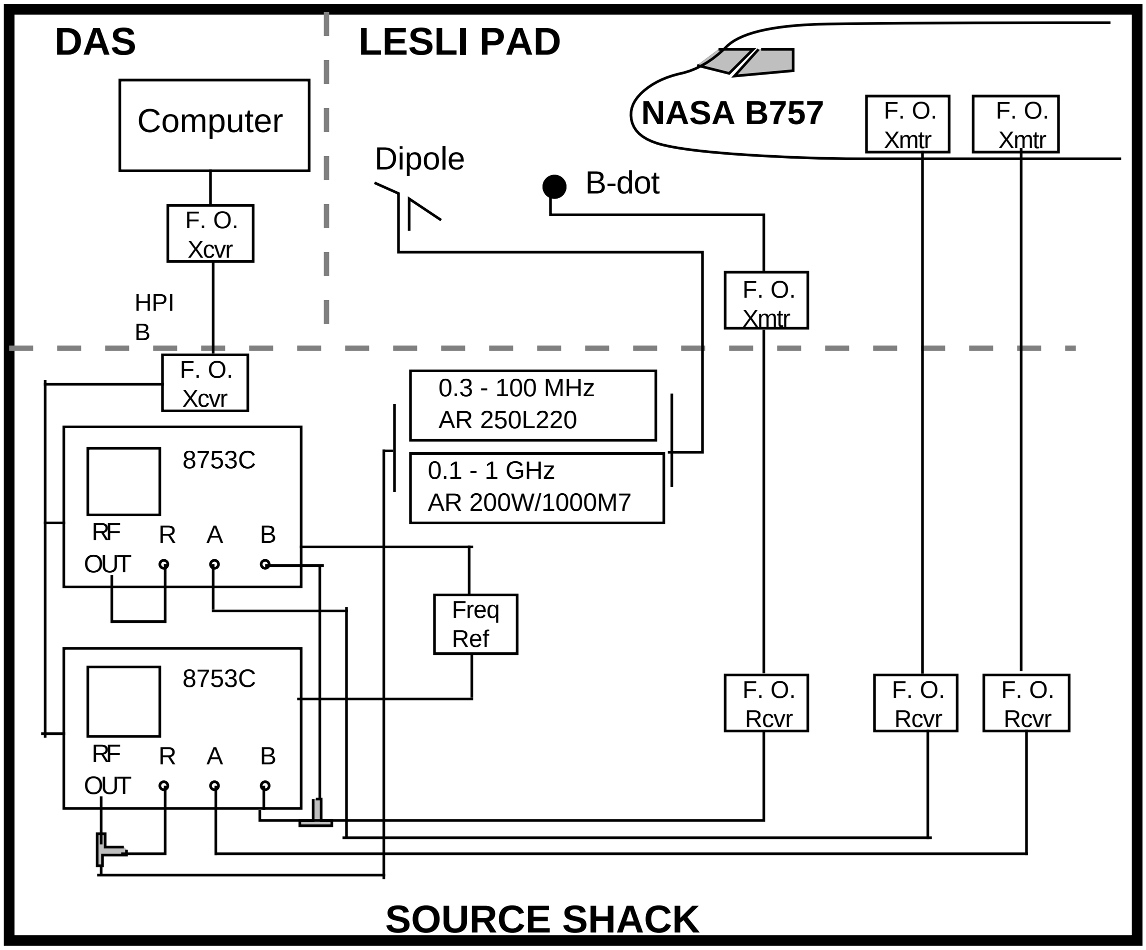


Figure 7.7-2. Dipole test instrumentation.

7.7.3.1 <u>CW Procedures</u>. The aircraft will be unpowered for these tests. The aircraft will be unmanned for this test series, although there is no RF hazard. The CW test points will be instrumented with the appropriate sensors as indicated on the detailed setup sheets. The probes will be connected to fiber optic transmitters; the outputs of the receivers will be connected to the network analyzer located in the source shack. On-board cables required to connect probes to the fiber transmitters will be supplied by LaRC. The network analyzers will be controlled by a control computer running the CWDAS software. CW sweeping will be accomplished using the FCC approved frequencies. Data acquisition (sweep) logs will be maintained by the Facility Operations Group.

Details of the data acquisition and processing to be accomplished are described in detail in the next subsection which also includes a detailed discussion of the acceptance criteria for data. Operationally, the Facility Test Director will follow the Test Point Matrix contained in this test plan and instrumentation setup sheets prepared by LLNL and Test Operations and Support. Facility Support will set up the appropriate DAS to acquire the requested test-points on any given sweep. When all are ready, the Facility Test Director will request that the sweep be initiated. The raw data

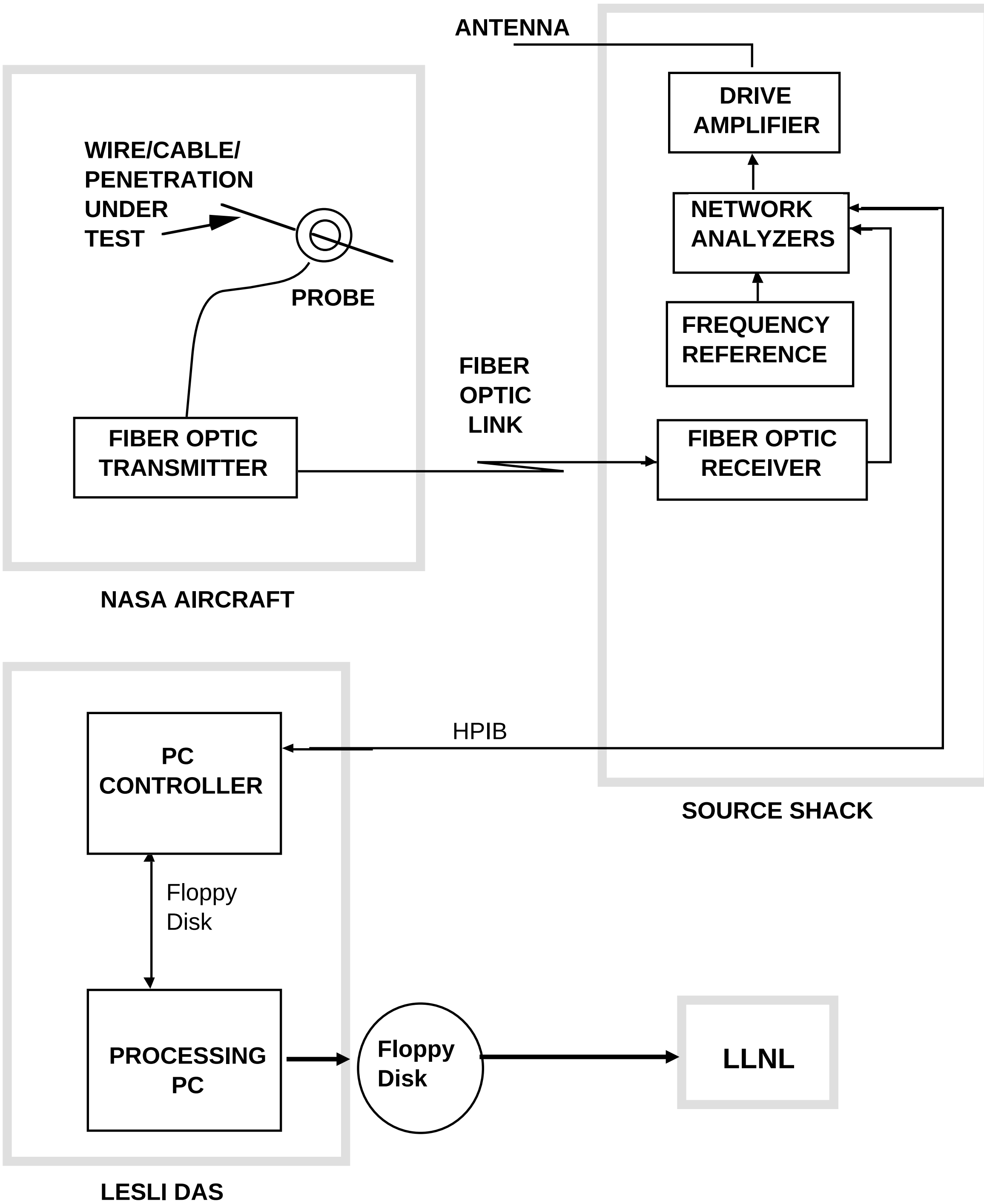


Figure 7.7-3. Example of CW data acquisition and processing flow.

will be displayed on the in-DAS monitors for immediate QC. After data acceptance based on the "immediate-QC", the data will be uploaded for further processing. Data that has gone through final processing as well as the raw data may be plotted and provided to the Test Directors. Data, including characterization/calibration files, will be provided to LLNL on floppy disks Data will be downloaded and archived in PCSLEET.

The Test Operation and Support Group will inspect the installation of the probes, cables, and links each evening after the last test. These will be inspected to insure that they have been properly placed, that they match the required test points, and that the instrumentation log sheets are correct.

7.7.4 CWDAS Data Acquisition, Processing, and Analysis

7.7.4.1 <u>CW DATA</u>

The following sections describe the data acquisition, quality control and data processing procedures to be used for CW test data.

7.7.4.2 <u>Acquisition</u>

CW data acquisition will be accomplished using the CWDAS hardware and software configured in a two-network analyzer setup. The data flow is identical in all cases. Figure 7.7-3 shows the acquisition setup and data processing flow. Each test point will be connected to a recording channel on an HP 8753C Network Analyzer via a NanoFast fiber optic link. Test frequencies will be linearly spaced between skipbands but will have a logarithmic distribution over the broad frequency range and will use the start, stop, and frequency steps shown in Table 7.7-1. These may be modified by transmitter VSWR or FCC restrictions. Due to FCC restrictions, data will be acquired using the allowable transmit bands as listed in the CWDAS manual. Note that there are two skip bands in the 26 MHz dipole band, one skip band in the 172 MHz dipole band, and two skip bands in the 430 MHz dipole band. Once a sweep has been completed, the data will be reviewed on the screen of the controlling personal computer. Instrumentation changes will be made and the data retaken as necessary. The acceptance criteria for the in-DAS QC of the CW data are listed in Table 7.7-2. Once accepted, the data, which include the measured variable at each test point and each frequency point, will be saved to the hard drive in the personal computer. The data will be periodically, at the direction of the Test Director, translated into TSA format and uploaded to the processing PC.

Table 7.7-1. Frequency tables for Dipole Tests (MHz)

f(test)	f(start)	f(stop)	f(step)	# freq	frequency skip bands
25.085	23.00	28.00	.005	1001	24.99 to 25.10, 25.55 to 25.67
172.00	155.00	189.00	.034	1001	162.375 to 162.575
430.00	387.00	473.00	.086	1001	401.60 to 402.20, 406.00 to 406.10

Table 7.7-2. In-DAS QC criteria for CW data.

1. Sufficient attenuation/gain has been used to prevent an overload or noise floor corruption of the network analyzer.
2. The peak of the recorded waveform is greater than -10 dBm for full scale screen deflection.
3. All header data is the same as that recorded on the data setup sheets.

7.7.4.3 Processing in TSA

As part of the uploading process into TSA, the data will be processed as described in Table 7.7-3.

Table 7.7-3. TSA processing steps for CW data.

1. Correct the data for probe/link, etc., frequency dependent and linear scale factors and save it as a .COF file.
2. Plot the following for use by QC:
   Raw frequency (.RAW)
   Corrected frequency (.COF)

The plots indicated in Table 7.7-3 will be used as they are available by Test Support/QC to ensure the quality of the processed data. Data sets returned for reprocessing will be documented on a User Change Request (UCR). Each UCR will identify the test point, the shot number, and what specific reprocessing is requested. Upon completion of the correction, UCRs will be filed in the original data folders. The QC criteria for TSA processing are listed in Table 7.7-4.

Table 7.7-4. TSA QC criteria for CW data.

1. Probes/links/etc. have been properly u folded from the data.
2. Final frequency dependent magnitude data look reasonable.

7.7.4.4 Processing in PCSLEET

Prior to the start og the test, alm of the characterization files will be loaded onto the LESLI processing PC as well as loaded knto PCSLEET. Field mapping and test data will be uploaded to the LESLI processing PC running MatLab for processing. Raw and processed data will be loaded into PCSLEET. During this process the header data and archive will be checked using the criteria listed in Table 7.7-5.

Table 7.7-5. PCSLEET Processing QC Criteria for CW Data

1. Header information is complete.
2. Only one data set is archived for each test point/test shot. (NOTE: Multiple sweeps may be taken at many test points. However, only one measurement will be archived for each test sweep.)

Note: Final data files will be immediately backed up by copying to an auxiliary storage medium such as copying to disk, the Boeing 720B database or PC disk.

7.7.5 Noise Measurements

The noise environment will be characterized in order to quantify measurement quality, dynamic range, and error bounds. During these experiments, noise sources will be defined as arising from two sources, namely, the ambient environment and instrumentation.

The ambient noise will be established soon after the NASA 757 is in position on the pad and will be used as the standard for the entire test program. For the purposes of characterizing the ambient environment, four distinct measurements will be made. Using measurements made with two probes in the cockpit (vertical and transverse electric field probes), a cable current probe in the electronics bay, and an external VHF blade antenna on the airplane, a spectral map will be constructed of the noise environment.

Instrumentation noise for the dipole tests will be carried out for each specific frequency range and dipole polarization. The instrumentation noise measurements will be executed after each test sequence is performed. The strongest and weakest set of data in each sequence will be identified. Then, the corresponding probe will be removed, replaced by a matched load, and a data measurement sweep performed. The resulting data will provide an indication of the instrumentation noise at the lowest and highest gain settings for the data acquisition system.

7.7.6 Test Matrix for Dipole Tests

A detailed test matrix is presented in Appendix C. The dipole tests are series A through F. Tests are shown in prioritized order so that if insufficient time is allotted, the lower priority tests can be dropped. Estimates of the duration of each test are also shown in Appendix C.

7.8 Fixed CW and Pulsed Measurements with On-Board Instrumentation

This on-the-ground test series is intended to validate the instrumentation required for the fly-by tests. These tests would also allow a comparison between the power coupled to the aircraft interior both on and off the ground and would validate the modeling code's ability to predict this difference. In addition to determining whether the system can measure and record the RF signals, an equally important aspect of these tests is to determine whether the measurement system can measure the RF signals in the presence of noise generated by on board electronic systems.

These tests will be made with aircraft power supplied by the on-board auxiliary power unit (APU). If aircraft electronic systems can be powered (though not operating) when the aircraft is illuminated with RF, then all aircraft and experimental electronics systems will be powered to simulate the noise environment expected for the fly-by. If powering of the aircraft electronic systems (other than those associated with the power system) is not permissible, then the test series will necessarily proceed in two stages. Namely, with all electronic systems powered and no RF, the signals will be measured to provide an indication of the noise environment. Then, with all electronic systems off and RF on, the test series will be repeated. Clearly, this requires twice as many measurements as when allowed to have RF and all electronic systems powered simultaneously and somewhat compromises the test of the measurement system. The tests referred to in the preceding are denoted G, H, and I. Should a double set of runs be required, the noise background measurements will be referred to as G1, H1, and I1.

The aircraft will be manned by LaRC ground crew and experimental systems operator personnel and by LLNL personnel. No upsets are expected for any installed aircraft hardware. Section 7.12.3 and Appendix B deal with the RF levels expected to be encountered.

Since this is not a certification test, there will be no need to test a large number of frequencies Three frequencies have been chosen to match those selected for the fly-by tests. The illumination will be provided by the two-wire rhombic antenna configured in its common-mode configuration for vertical polarization. A fixed-frequency CW RF source will drive the appropriate LESLI RF amplifier. The UHF source will also be operated in a pulsed mode to simulate the pulsed radar planned for the fly-by (Wallops Island ASRF Radar).

7.8.1 Sensors

The sensors for the on-the-ground on-board instrumentation check-out tests will be the same as those used for the fly-by tests. These are a subset of the sensors used for the on-the-ground tests described in Section 7.5. The suite of 7 sensors will consist of one in the cockpit, two in the electronics bay, and four in the cabin. The cockpit sensor will be the vertically polarized D-dot on the sensor box. The electronics bay sensors will consist of the D-dot and cable current probe. All four of the cabin probes described in Section 7.5 will be included in the fly-by sensor suite.

The modified Collins VHF-700 transceiver box (RC-7) within the electronics bay will be removed for these tests so that the unqualified box will not be on the aircraft bus when aircraft power is applied.

7.8.2 Test Instrumentation

The instrumentation for these tests will be quite different from the stepped frequency experiments. It consists of spectrum analyzers and oscilloscopes rather than a network analyzer. The instrumentation will be provided by NASA LaRC and will already be installed into the aircraft and checked out prior to the aircraft's arrival at PL. A block diagram of the instrumentation is shown in Figure 7.8-1.

<u>7.8.2.1 RF Instrumentation</u>

RF signals from antennas and sensors will be multiplexed to the RF instrumentation by switches. These switches will be computer controlled in order to select the proper antenna and sensor for each test. Amplitude or power measurements will be made in real time on each of two external or internal RF probe channels simultaneously. A 2-channel digitizing scope will be employed for absolute voltage measurements. A pair of spectrum analyzers will be used for power measurements.

Data acquisition and instrument control will be computer based. An automated system will be used to maximize data returned during the fly-by tests. There will be minimal operator intervention during simulated in-flight data collection; all sensors will be recorded within a few seconds.

7.8.3 Set Up

The aircraft will remain in the same location as for the previous set of dipole tests. The LESLI rhombic antenna will be installed for common mode, vertical polarization operation by Test Operations and Support. The source will be connected as shown in Figure 7.8-2.

Sensor cables will be disconnected from the fiber optic links by PL/UIE personnel and reconnected to the on-board instrumentation by LaRC or LLNL personnel once disconnected from the on-board FO transmitters.

7.8.4 On-Board Equipment Test Procedure

Aircraft power will be applied by the LaRC ground crew. The on-board instrumentation will be powered up by the LaRC experimental systems personnel. The aircraft will be manned during this test series. A block diagram of the on-board instrumentation set up is shown in Figure 7.8-1.

On-board personnel and transmitter source operators will be in communication via walkie talkies. Once the instrumentation has been determined to be operational, the on-board experiment director will request that RF power to the rhombic antenna be turned on. RF power will be applied for a period of 30 seconds, unless either the Experiment Test Director or Facility Test Director requests power to be shut off earlier. This time period is estimated as the dwell time at a particular frequency that is likely to be acceptable by the FAA. Earlier tests in the LESLI have always been stepped and dwells at a frequency in the millisecond range have been acceptable. During this 30 second period, the automated on-board instrumentation will collect data. This procedure will be repeated until the instrumentation is operating satisfactorily

LaRC personnel will be responsible for archiving any data collected during the on-board experiments. LLNL, PL, and UIE personnel will assist as needed.

7.8.5 Test Matrix for On-Board Instrumentation Checkout

A detailed test matrix is presented in Appendix C. The on-board check-out test are series G through I. Tests are shown in prioritized order so that if insufficient time is allotted, the lower priority tests can be dropped. Estimates of the duration of each test are also shown in Appendix C.

7.9 Stepped CW Measurements: CWDAS with Rhombic Antenna

The instrumentation for this test series will be the same as described in Section 7.7, except that the rhombic antenna will be used instead of dipoles with a frequency range from 300 KHz to 1 GHz.

7.9.1 Set Up and Probe Installation

A block diagram of the stepped CW measurements made with CWDAS and the Rhombic antenna is shown in Figure 7.9-1.

Probes will be disconnected from the on-board instrumentation and reconnected to the fiber optic transmitters by Test Support and Operations.

7.9.2 Test Operations

The NASA aircraft will be pre-positioned for the start of these tests. During the test sequence, the aircraft will be moved up to four times. Repositioning of the aircraft will be accomplished by LaRC and Aircraft Operations personnel.

The PL/WSM LESLI Data Acquisition System (DAS)/CWDAS will be used to acquire CW data. Acquired data will be uploaded to the LESLI processing PC running MatLab for processing and distribution. Data will also be downloaded and archived into the PCSLEET data base.

The aircraft will be manned during portions of this test. There is no RF hazard to on-board personnel associated with these tests (see Sect. 7-11 and Appendix B). The antenna is the two-wire rhombic antenna described above.

The majority of the instrumentation resides in the Source Shack. The instrumentation will be controlled by a PC-based controller that resides in the LESLI DAS trailer. The LESLI DAS trailer is located off the side of the antenna. The Source Shack is located at the drive point of the antenna. With the exception of the NASA/LLNL provided probes, sensors, and cables, all of the required instrumentation will be provided by the Phillips Laboratory.

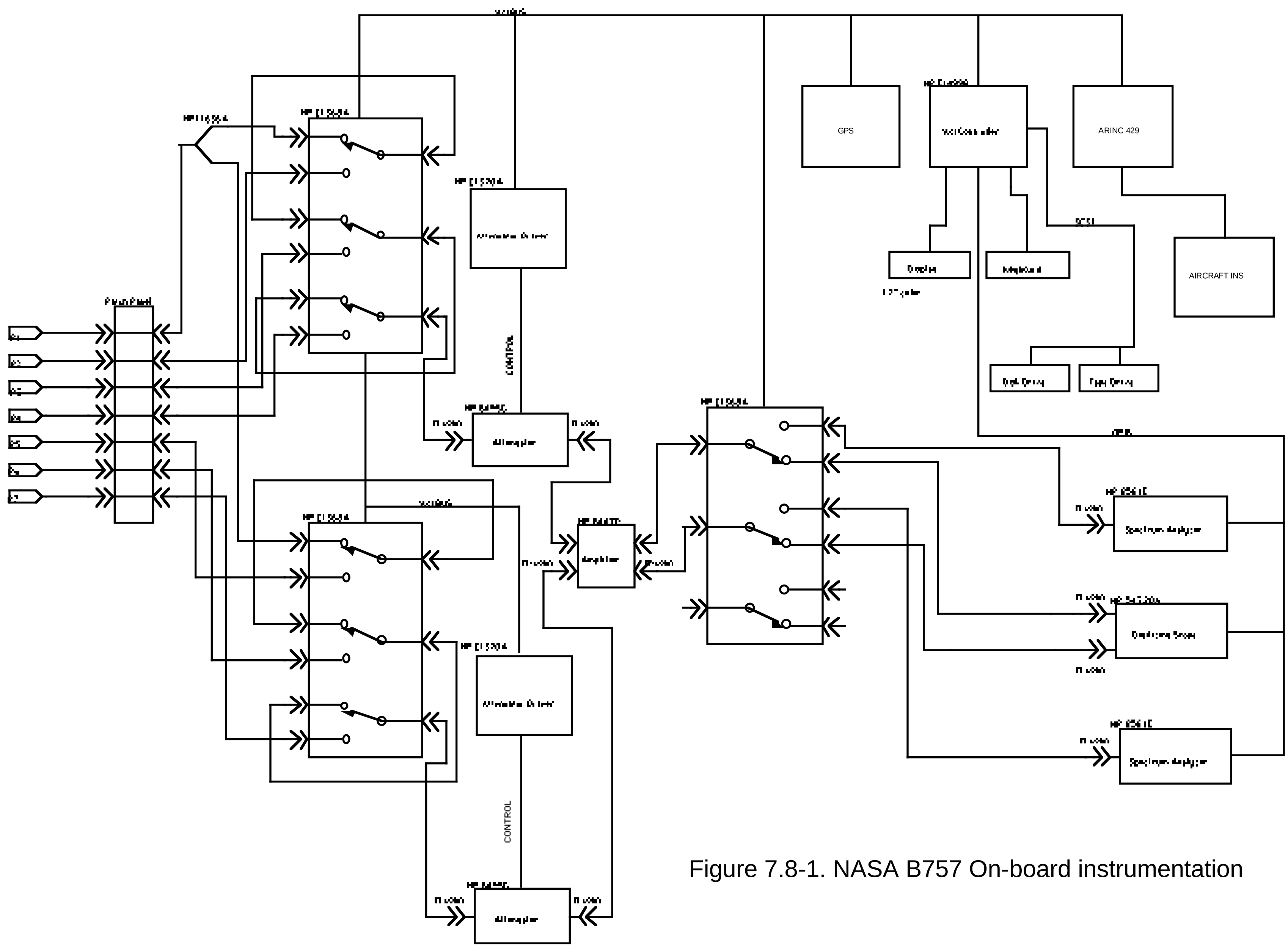


Figure 7.8-1. NASA B757 On-board instrumentation

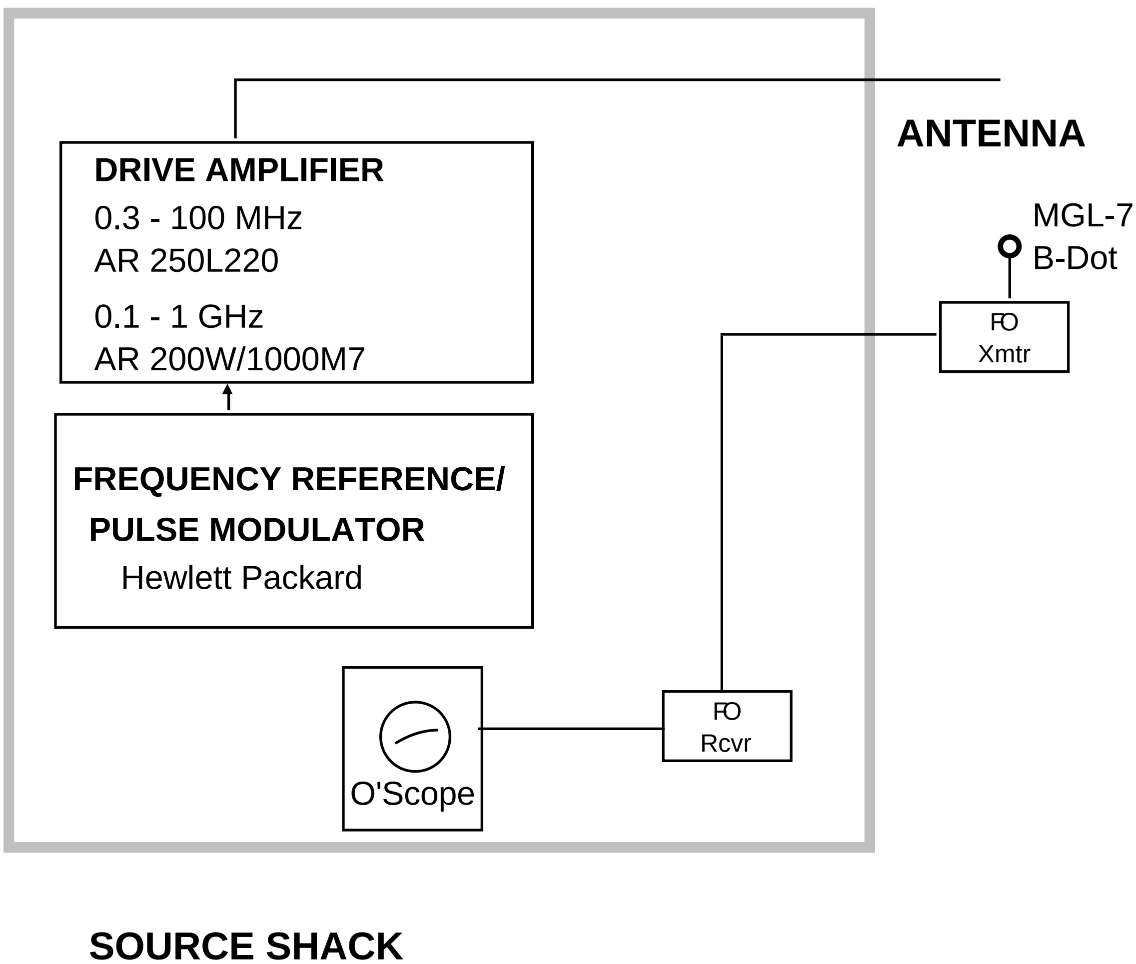


Figure 7.8-2. Source set up for on-board instrumentation check-out.

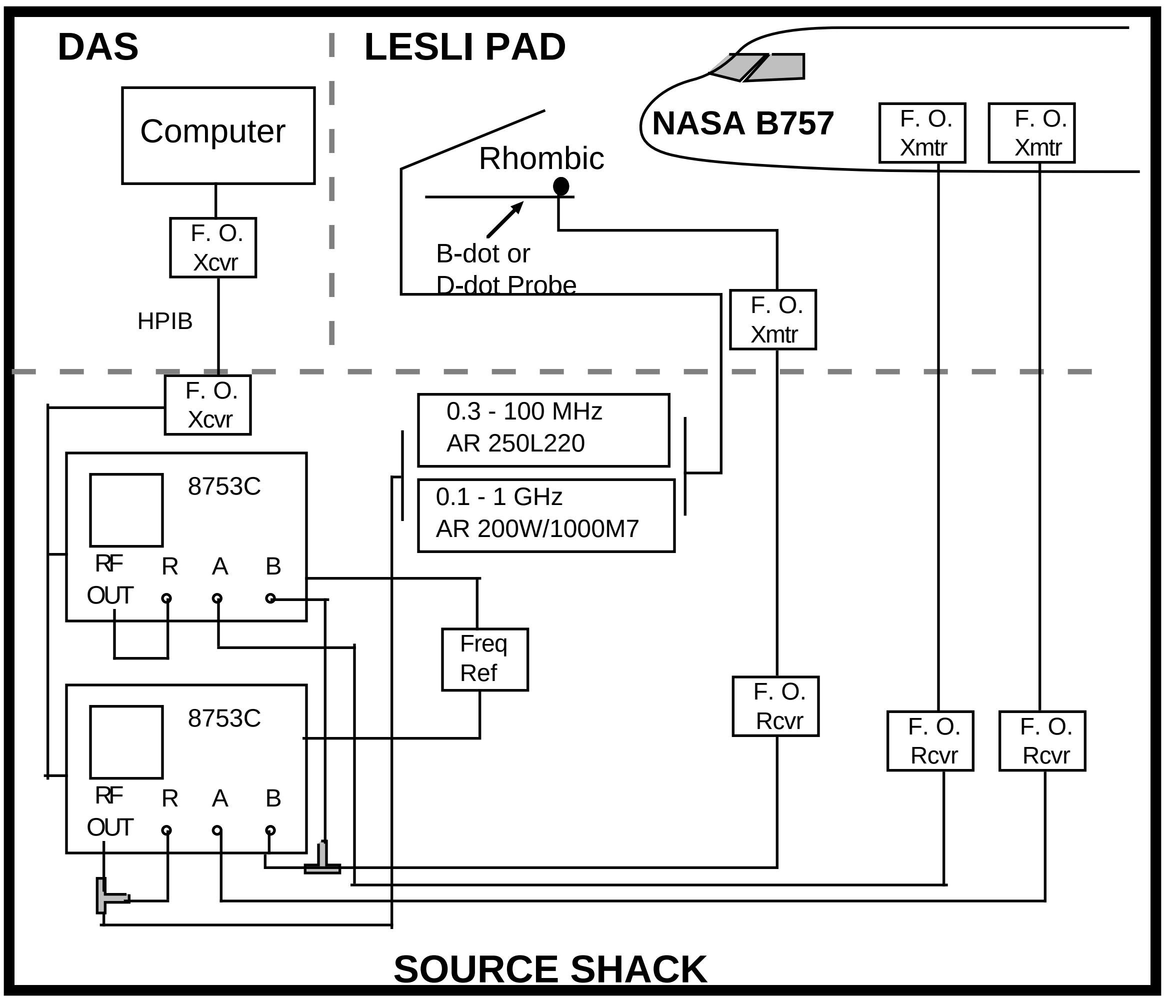


Figure 7.9-1. CWDAS instrumentation for stepped CW measurements with the rhombic antenna.

7.9.3 CWDAS Data Acquisition, Processing, and Analysis

Data acquisition, processing, and analysis will follow the same procedures described in Section 7.7.

7.9.4 Instrumentation Noise Measurements for Stepped CW

Instrumentation noise measurements for stepped CW measurements in the rhombic will be performed at the beginning of the rhombic test sequence. In the nose-on configuration, each data channel will, in turn, be tested. The probe on each channel will be removed and replaced by a matched load. Then under RF illumination in the rhombic, a complete sweep will be executed and recorded for that channel. The complete set of data will include a complete sweep for each channel and will represent the characterization of the noise floor for the measurements to be executed.

7.9.5 Test Matrix for Stepped CW Measurements with Rhombic Antenna

A detailed test matrix is presented in Appendix C. The stepped frequency tests with the rhombic antenna are series J and K. Tests are shown in prioritized order so that if insufficient time is allotted, vhe lower priority tests can be dropped. Estimates of the duration of each test are also shown in Appendix C.

7.10 Stirred Frequency Tests

7.10.1 Background

As discussed in Section 4.0 it is hypothesized that the power density at a point in an aircraft cavity can have a statistical distribution that is dependent on the variation in excitation conditions (e.g., aspect angle) and the cavity losses. This hypothesis is based on the assuÔption the aircraft cavity is complex and large enough to be multimoded at the lowest frequency of interest. There is theoretical evidence that there exists statistical distribution function which describes the aircraft cavity electromagnetic environment (EME) for all possible excitation conditions and cavity configurations[1] . The theoretical distribution function is independent of the details of the shape or size of the aircraft cavity, the location of cable bundles, and the location of metal boxes such as avionics systems. Except for a normalization factor to account for specific external to internal coupling efficiencies and aircraft cavity losses, normally characterized by the quality factor (Q), the statistical power density distribution is predicted to be independent of the particular cavity within the aircraft as well as the specific type of aircraft. These are very significant predictions which bear directly on how an aircraft's internal EME should be determined and how avionics systems should be tested.

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[1] Lehman, T. H., Paper presented at the Anechoic Chamber and Reverberation Chamber Operators Group Meeting, NSWCDD, Dahlgren, VA, Nov. 1992.

The limited experimental data base currently available[2,3,4] supports this hypothesis and agrees with the postulated theoretical distribution function.

This test will provide additional data from a current operational passenger-configured aircraft.

7.10.2 Specific Test Objectives

1. Determine the statistical characteristics of the B-757 cavity EME.
2. Determine the cavity Q by direct measurement of pulse decay time.
3. Determine cavity insertion loss.
4. Determine cavity-to-cavity coupling efficiency.

7.10.3 Approach

The characterization of cavity EME as described in this section will be performed with no power applied to any aircraft system. The test objectives will involve direct insertion of low power (< 1 watt) signals into the aircraft cavities. The signals will be inserted into an aircraft cavity using a wide band horn transmit (TX) antenna. The power density in the cavity will be monitored by a similar wide band receive (RX) antenna. To achieve the desired statistical distribution data, an effective technique for cavity mode-mixing is required. The most common approach to date has been to use a mode-mixing technique, band limited white Gaussian noise (BLWGN), has been developed at the USAF Phillips Laboratory. This technique has been compared with mechanical mode-mixing in standard reverberation chamber (or mode stirred chamber) test facilities[5]. A primary objective of the Phase II demonstration test on a B-707, performed in March 1994, was to compare the BLWGN technique with mechanical mode-mixing for characterization of aircraft cavity EME. The analysis of the test data is still in process, but to date no unexpected results have been found.

A specific advantage of using BLWGN over mechanical mode-mixing is a significant reduction in test time. The demonstrated reduction in data acquisition time in the B-707 Phase II test was approximately a factor of 4.0.

Figures 7.10-1 and 7.10-2 show the test instrumentation for characterizing the aircraft cavity EME using the BLWGN excitation technique. The control, stimulus, and measurement module, shown in Figure 7.10-1, contains the computer controller and plotter used to control the test equipment, acquire data and display data.

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[2] Hatfield, M.O., Freyer, G.J., Johnson, D.M., and Farthing, C.E., Electromagnetic Reverberation Characteristics of a Large Transport Aircraft, NSWCDD/TR-93/339, July 1994.

[3] Hill, D.A., Crawford, M. L., Johnk, R. T., Ondrejka, A.R., and Camell, D.G., Measurements of Shielding Effectiveness and Cavity Characteristics of Airplanes, NISTIR 5023, July 1994.

[4] Loughry, T. A., Hatfield, M.O., Freyer, G. J., Johnson, D. M., Ondrejka, A. R., and Johnk, R. T., Phase II Demonstration Test of the Electromagnetic Reverberation Characteristics of a Large Transport Aircraft, NSWCDD/TR, In Process.

[5] Crawford, M.L., Loughry, T.A., Hatfield, M.O., and Freyer, G.J., Validation of Band Limited, White Guassian Noise Excitation of Reverberation Chambers and Verification of Applications to Radiated Susceptibility and Shielding Effectiveness Testing, NIST TR, In Process.

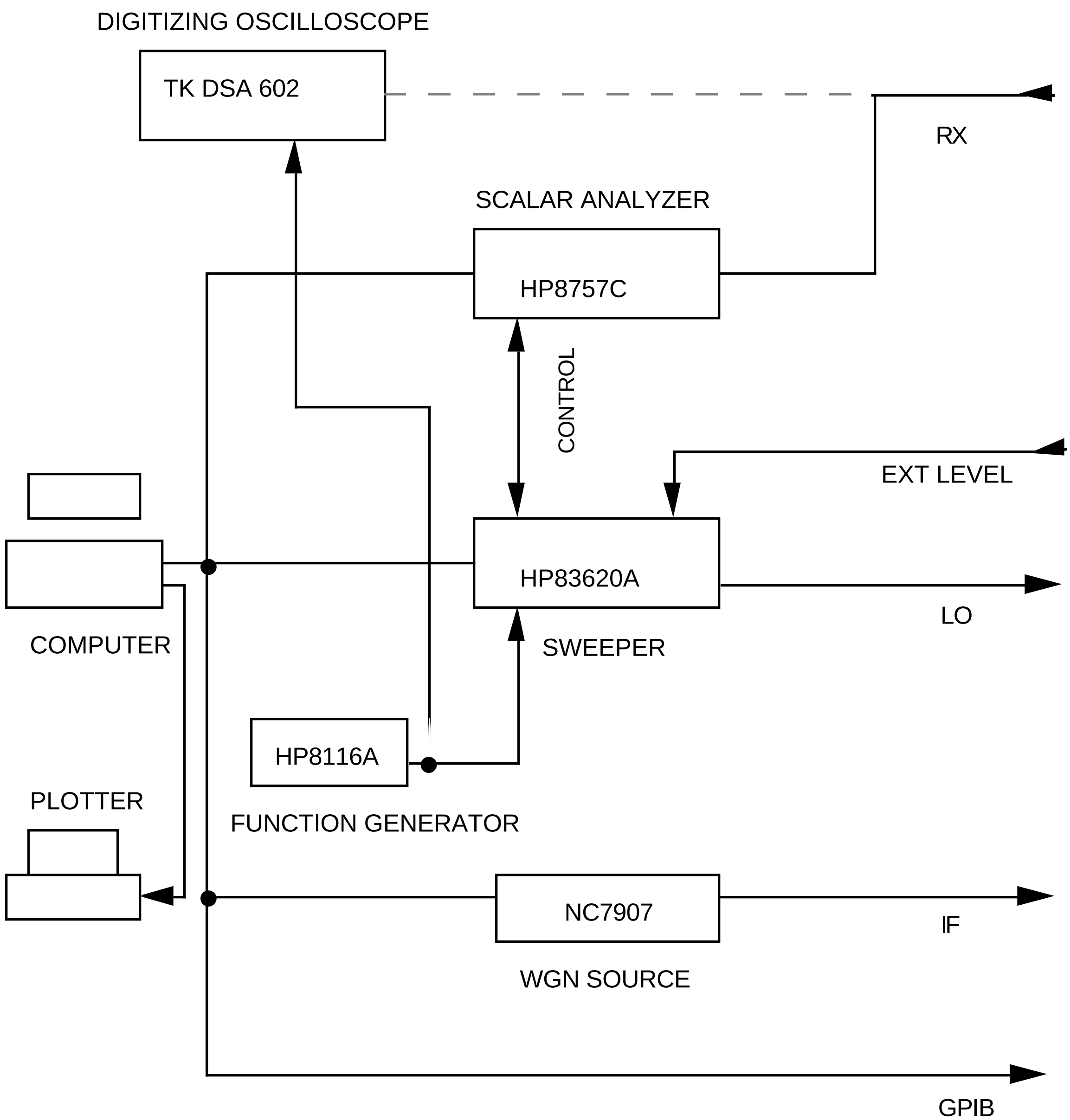

Figure 7.10-1. Control, stimulus and measurement module

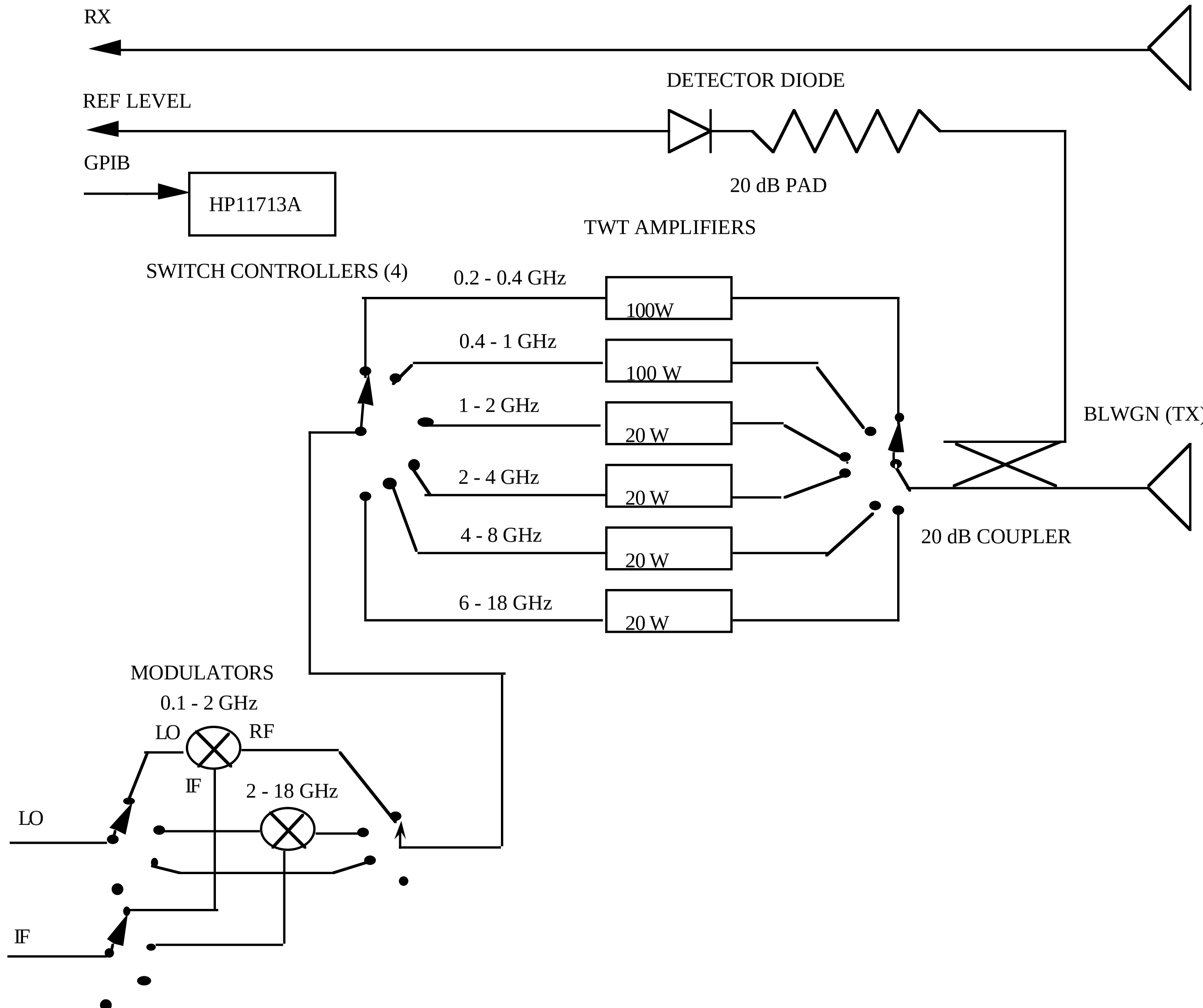

Figure 7.10-2. Modulator, amplifier, and switching module

The sweeper generates the local oscillator signal which will cover the range 0.5 to 6 GHz for this test. The WGN source generates noise at the proper bandwidth (50 MHz for this test) as commanded by the computer.

For test objectives 1, 3, and 4 the function generator produces either a discrete frequency or a swept frequency continuous wave (CW) signal. The scalar analyzer is used to measure the signals from the RX antenna.

For test objective 2, the function generator produces a discrete frequency, repetitively pulsed signal. A wide range of pulse repetition rates are available within the capabilities of the instrumentation system. Based on previous aircraft test experience, a 1 KHz rep rate has been found to provide adequate accuracy and reasonable data acquisition times. A 1 KHz rep rate will be used in this test for direct measurements of all aircraft cavity Q values. The digitizing signal analyzer (DSA) is used to measure the pulse decay time of the signals from the RX antenna.

The modulator, amplifier and switching module, shown in Figure 7.10-2, performs the up-conversion and amplification of the noise to produce the BLWGN signal. Part of the BLWGN signal is sampled and diode detected to provide an external level reference signal for the sweeper in Figure 7.10-1. The external level reference ensures that the BLWGN signal at the TX antenna remains constant despite varying amplifier gain and cable losses. The power radiated into an aircraft cavity will be controlled to be 1 watt or less. The switch controller selects the appropriate modulator and amplifier combination for the frequency being generated.

The transmit antenna locations and orientations are selected such that they are directed toward appropriate metal reflecting surfaces (e.g., the pressure hull, compartment walls, etc.) in each aircraft cavity. In no case will the TX antenna be directed toward aircraft electronic systems. Two TX antenna locations are defined for the cockpit and passenger cabin. Due to space limitations only one TX antenna location is defined for the electronics bay. These locations are identified in Figure 7.10-3 and described in Table 7.10-1.

Table 7.10-1. Transmit Antenna Location, Orientation and Polarization

Num	Cavity	Location	Orientation	Polarization
#1	cockpit	3’ forward of cabin door 3’ above floor on aircraft center line	225^o from nose 45^o above horizontal	vertical
#2	cockpit	3’ forward of cabin door	vertical	parallel to aircraft center line
#3	electronics bay	centered between electronics racks (approx. 52” from rear electronics rack), 12” above platform, 24” left of center line	270^o from nose	horizontal
#4	cabin	on aisle seat approx. 12’ forward of main cabin door	vertical	transverse to aircraft center line
#5	cabin	on aisle seat approx. 3’ rear of main cabin door	45^o off vertical	parallel to aircraft center line

Several RX antenna locations will be used in each aircraft cavity. The RX antenna is passive and does not present any hazard to on board electronics systems. The RX antenna will be placed to obtain the desired aircraft cavity EM characteristics. The RX antenna will be located to avoid direct illumination by the TX antenna. A minimum of four RX antenna locations/orientations/polarizations will be sampled in each aircraft cavity. If test time permits, additional RX antenna locations/orientations/polarizations will be sampled in the cockpit and passenger cabin.

Coaxial cables will be attached to the TX and RX antenna feed points. These will be routed through the electronics bay or passenger cabin to the pressurization equalization port in the same manner as the sensor fiber optic cable for the primary test points. The coaxial cables installed for the cockpit ATOPS sensors will be used for the BLWGN TX and RX antennas.

Note that installation of all cables and placement of antennas will be coordinated with NASA aircraft operations personnel.

Sucoflex cable will be used from a point just inside the aircraft to the instrumentation cart located some distance from the aircraft. The Sucoflex cables have a highly attenuating cover which will minimize energy leakage into the aircraft. This approach will compensate for not using the standard isolating feed-throughs at the aircraft pressure hull.

The test matrix for the BLWGN excitation is given in Table C-22 in Appendix C.

7.10.4 Test Organization

The principal investigator on the BLWGN excitation test will be Capt. T. Loughry, PL/WSM. He will be assisted by SSgts. D. Little and C. VanZandt, also of PL/WSM. One or more of the following may also participate in this test: M. Hatfield, Naval Surface Warfare Center, Dahlgren Division; G. Freyer, Universal Systems, Inc.; and/or M. Johnson, Computer Science Corp. All of the above personnel have participated in at least one aircraft test using the BLWGN excitation technique.
All test instrumentation and data processing will be provided by Capt. Loughry. PL/WSM will designate a safety officer for the BLWGN test. All remaining organizational support function will be the same as on the primary test.

7.10.5 Pretest Procedures

Other than the aircraft survey which led to selection of the TX antenna locations, no special pretest activities are required.

The instrumentation, setup, and data acquisition and processing to be used for this test is the same as that employed on the recent B-707 test conducted by PL/WSM. All instrumentation and data acquisition software are available.

Calibration runs are performed on the “as installed” instrumentation, cables, and connectors.

7.10.6 Safety

During the BLWGN excitation test, all RF emissions will be within the aircraft and the aircraft will not be manned, therefore no test unique personnel safety hazards exist.

The aircraft can remain grounded throughout the BLWGN test.

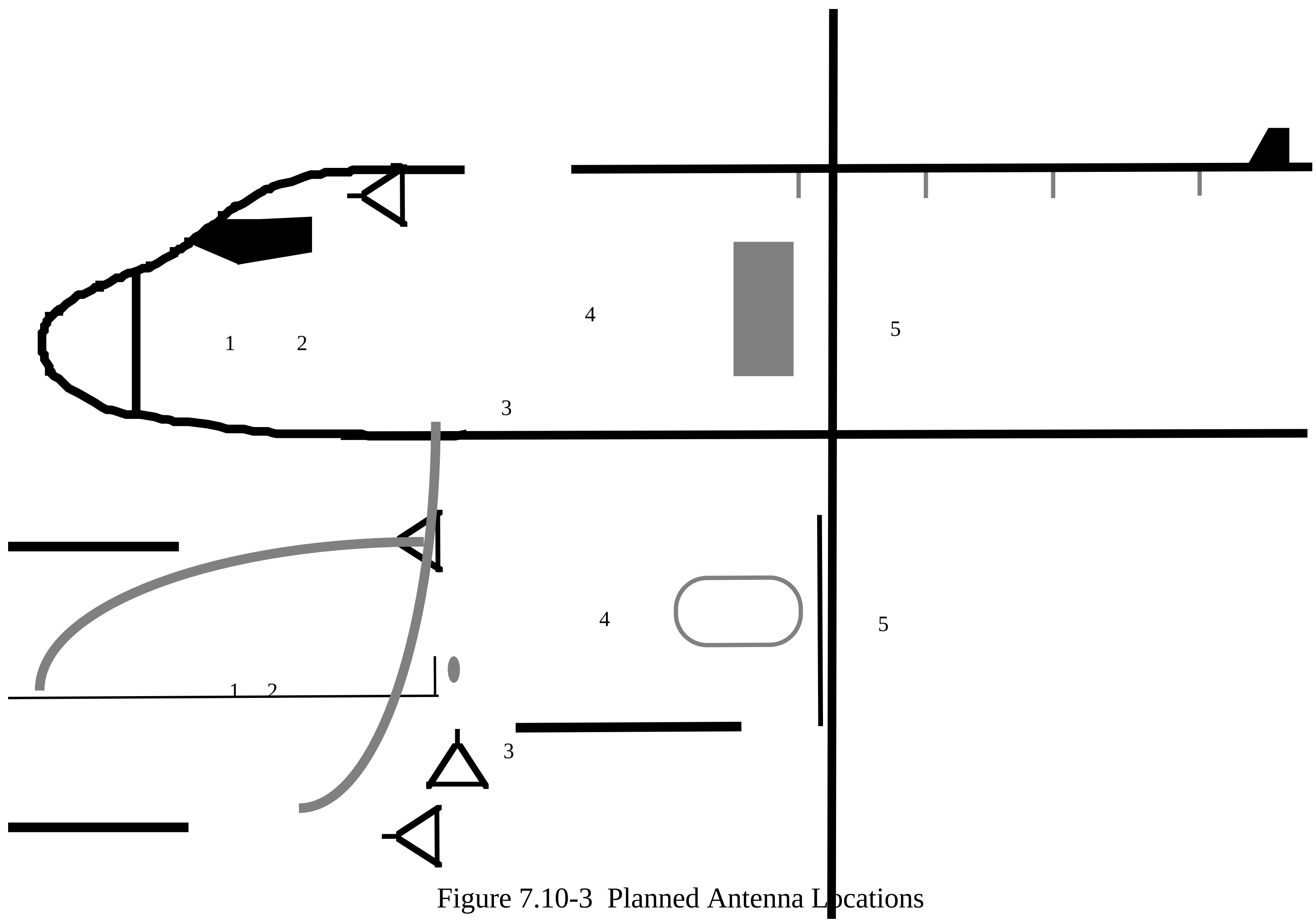

Figure 7.10-3 Planned Antenna Locations

Note all test personnel access to the aircraft will be coordinated with the NASA aircraft operations personnel.

The safety issues and procedures for this test are the same as for the pertinent Sections of 7.12.

7.10.7 Risk Analysis for Aircraft Electronic Systems

If a directional TX antenna were pointed directly at an on board electronic system one meter from the antenna, the worst case field strength could be as high as 10 v/m. Standard mode-mixing test procedures avoid direct illumination of test objects since this test configuration will bias the test results. In this test special care was taken in selecting TX antenna configurations to preclude direct illumination of any aircraft systems.

The mode-mixing accomplished through the BLWGN technique, in the ideal case, provides a uniform, isotropic, randomly polarized EME throughout the cavity. The power density in the cavity will depend on the Q and volume of the cavity and the input power. Using the following equation derived from material in reference[6]

$$E(v / m) = 0.02 * \left(Q * \lambda * P_{in}(w) / Vol\left(m^3\right)\right)^{1/2}$$

the estimated worst case power density is less than 14 v/m. This value is based on the maximum input power of 1 w, on an estimate of the smallest test cavity volume in the B-757, and the maximum of all Q*λ values available from the B-707 tests. This last value was an isolated data point which was at least a factor of two higher than any other test data.

Since no power will be applied to any aircraft electronics system, these worst case estimates for the BLWGN test should present no risk to the on board electronics systems of the B-757.

7.11 On-the-Ground Test Schedule

The overall test schedule is presented in Figure 7.11-1. This schedule may be modified by the Test Director.

7.11.1 Daily Test Schedule

A typical test day for the stepped frequencies tests includes 8 hours of actual measurement time and additional time for preparation and stand-down of the site. A typical day will consist of the following:

a. Open site/site prep at 0630
b. Stand-up meeting at 0645
c. First measurement at 0715 hours
d. Lunch break 1100-1200
e. Last measurement at 1615
f. Meeting (TOWG) approximately 10 minutes after the last sweep
g. Data transfer complete/site secured by 1700

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[6] Crawford, M. L., and Koepke, G.H., Evaluation and Use of a Reverberation Chamber for Performing Electromagnetic Susceptibility/Vulnerability Measurements, NBS TN 1092, 1986.

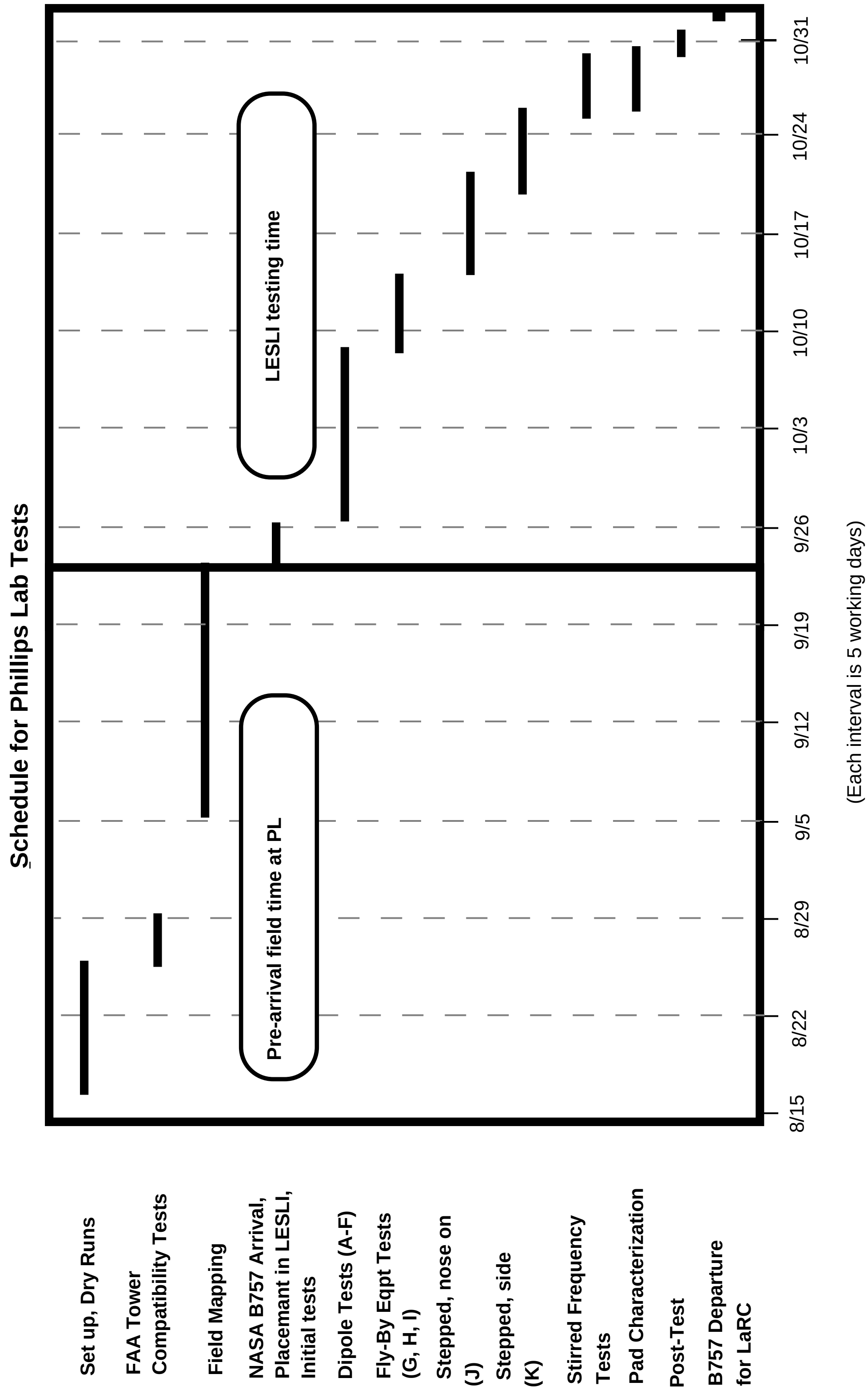

Figure 7.11-1. On-the-ground test schedule.

7.12 Safety

Performance of test operations in a hazardous manner can result in personnel injury, loss of life, or equipment damage. Serious mishaps can also affect meeting planned test objectives. This section summarizes data presented in more detailed hazards analysis and system safety program documentation and provides details for this specific test.

7.12.1 Documents List

The documents which define the applicable safety requirements and provide safety information are listed below:

(a) System Safety Program Plan, UIE-TR-88-0009, 22 Apr 1988
(b) Preliminary Hazards Analysis, UIE-TR-88-0010, 15 Apr 1988
(c) MIL-STD-882A, System Safety Program Requirements, 28 Jun 77
(d) Code of Federal Regulations, Title 29, Parts 1910 (Feb 83) and 1926 (Mar 83), (Occupational Safety and Health Act (OSHA))
(e) AFR 127 Series (-2, -4, -7, -8, -12, and -100)
(f) AFOSH 127 Series (as applicable)
(g) AFOSH 161 Series (-1 through -9 as applicable)
(h) AFPLR 127-3, Air Force Phillips Laboratory Regulation, Systems Safety Requirements

7.12.2 Documentation Overview

Document (a) is the System Safety Program Plan for the Boeing 720B. It establishes the basic system safety program for the maintenance and use of the Boeing 720B.

Document (b) is the Hazards Analysis for the Boeing 720B. It covers all of the potential hazards associated with the use of the Boeing 720B and discusses the efforts to reduce all known hazards to acceptable safety levels.

Document (c) is the source of the major safety requirements. It is required in the UIE contract.

Document (d), Code of Federal Regulations (Title 29, OSHA), is a broad and detailed delineation of general safety standards for industry. It covers a wide variety of occupations and working conditions to be considered in developing safe operating procedures.

Document (e), AFR 127 Series, provides information and guidelines on safety responsibility, safety program components, safety hazard abatement, and Department of Labor Inspections and Evaluations within the Air Force.

Document (f), AFOSH 127 Series, provides guidance for Air Force-wide and industrial safety accident prevention programs. It explains the hazards in and prescribes safety precautions for operating industrial equipment. It is designed to augment other Air Force publications and covers such subjects as the fundamentals of accident prevention, safety practices in construction and maintenance, health hazards and protection, fire protection, and safety in materials handling.

Document (g), AFOSH 161 Series, relates to health and environmental conditions such as radio frequency radiation, permissible exposure limits, carcinogenic substances, and other health subjects.

Document (h), AFPLR 127-3, establishes a Technical Safety Committee within the Phillips Laboratory and describes safety review procedures. The document specifies that all experiments include an Emergency Action Plan which provides: (1) the general requirements and methods for alerting personnel of an emergency, and (2) the appropriate actions to be taken to respond to the emergency.

7.12.3 Hazards Analysis

The aircraft test environment during the tests, both under illumination during the dipole tests and the tests within the LESLI facility using the rhombic antenna, has been determined to be below the levels that might present a hazard to on-board electronic systems and to humans. Further discussion of this issue is found in Appendix B. In addition, an on board electric field sensor, such as a Narda 8616, will be used to provide a real time indication of field strengths when the sources are operational and personnel are present in the airplane.

Many hazards associated with the NASA aircraft are similar to those associated with the PL Boeing 720B aircraft noted in the document Preliminary Hazards Analysis, UIE-TR-88-0010, 15 Apr 1988, which was prepared for the operation, maintenance, and use of a Boeing aircraft in EM testing experiments. The reader is directed to these documents for detailed discussions of the hazards and their mitigation to acceptable levels.

7.12.3.1 Facility SAFETY PROGRAM

Fundamental to a responsive and responsible safety program is implementation of the concept that anyone who detects an unsafe condition has the responsibility to alert the rest of the test team and immediately stop the hazardous operation(s). This section presents the safety program to be enforced for the facility.

7.12.3.2 Safety Organization

Ultimate responsibility for ensuring safety throughout the program resides in the Facility Test Director. Responsibility for implementation of all safety measures on-site will be delegated by the Facility Test Director to the designated Safety Officers as listed in Table 7.12-1. Each Test Safety Officer will ensure that the safety rules and procedures established by the PL are followed. The Facility Test Director will determine when conditions are safe for testing, including restart of test operations after an unsafe condition has been detected. The Facility Test Director will make this decision after consulting with each Safety Officer, who has direct access to the Facility Test Director. The responsibilities of each safety position are described in the following paragraphs.

Table 7.12-1. Test safety assignments.

Title	Name	Office	Test Site
Facility Test Director:	Mr. L. Dao	505-846-0995	846-5998
NASA Aircraft Safety	Mr. M. Basnett	804-864-3900	
Site Aircraft Safety:	Mr. R. Christianson	505-846-1177	822-4702*
Site / Operation Safety:	Mr. Don Lin	505-846-0995	846-5998

* Pager Number

7.12.3.3 Facility Test Director. The designated Facility Test Director has the overall authority to execute and implement those efforts required to achieve safe operation. He will be supported by specifically designated personnel in each of three areas: (1) Test Operations , (2) Aircraft Operations, and (3) Facilities.

7.12.3.4 Test Operations Safety. This individual is responsible for safe operations during test setup, preparation, and aircraft instrumentation.

7.12.3.5 Aircraft Operations Safety.(NASA and Site) These individuals are responsible for safe operations in and around the NASA aircraft while at the Phillips Lab.

7.12.3.6 Facility Safety. This individual is responsible for the safety of facility operations including data acquisition equipment, DAS operations, weather impacts, and general facility O&M.

7.12.4 Safety Procedures

The procedures that are needed to ensure safe operations for the facility fall into three categories: (1) normal site safety operations, (2) NASA B-757 operations, and (3) procedures unique to test operations.

7.12.4.1 Normal Safety Operations

7.12.4.1.1 Site Safety

The Facility Support will set up safety barricades and signs for the test pads. A site safety briefing will be conducted prior to the start of work. Important considerations include:

(a) The use of physical barriers such as safety ropes and fences to limit personnel access into hazardous areas,

(b) Limits on the number of personnel allowed into the hazardous area,

(c) Establishment of functions, procedures and locations for personnel required in the hazardous area,

(d) Control of general personnel access to the facility from a safety standpoint,

(e) Control of personnel access to the site and in the site working volume during the direct drive and CW test operations,

(f) Provision of safety equipment and instructions for its use, and

(g) Regular inspection and checkout of safety equipment.

7.12.4.1.2 Area Signs. All hazardous areas require proper marking and identification so personnel not familiar with hazards in the area are made aware of the dangers. General guidelines for this type of activity are contained in both AFR 127-101 and OSHA Safety and Health Standards 29CFR 1910; 2206, revised Nov 7, 1978. A detailed discussion, therefore, of area posting requirements is not repeated in this supplement.

7.12.4.1.3 Access to Area. As one consequence of the security requirements of the test sites, access is limited to those personnel who have a definite need to be in the area. This supports safety considerations by limiting the number of people in the working areas. During times of hazardous operations, the Facility Test Director and Test Safety Officers will have complete control over the operations on the site and of access to the working areas. They will be able to suspend or terminate any test activity at their sole discretion, if in their judgment, safety is being compromised. Any visitors wishing to go within the controlled test area must get the permission of the Facility Test Director (or his delegate) prior to entering. PL will provide Contractors and Government organizations with any special site safety equipment that may be required such as hard hats, radiation detectors, etc.

7.12.4.1.4 Safety Equipment. The on-site safety equipment is divided into three classes:

- (a) First aid equipment,
- (b) Personal safety equipment, and
- (c) Special safety equipment.

Adequate first aid equipment is currently located at the sites, and site personnel are trained in first aid techniques. Individuals performing hazardous operations, such as working on and around the test stands, will be required to use proper safety equipment to minimize hazards. Contractors and Government organizations which have personnel operating on the site will provide safety equipment for their personnel.

7.12.4.1.5 Personnel Safety Briefing. Safety procedures are only effective when adhered to. Each Test Safety Officer will ensure all test personnel receive a safety briefing prior to the start of testing at each test site. All personnel will be briefed in the following areas:

- (a) Performance of daily tasks in a safe manner,
- (b) Adherence to safety procedures for hazardous operations,
- (c) Observance of all warning signs in the area,
- (d) Continual examination of the site and test operations for potentially dangerous activities and conditions,
- (e) Adherence to emergency procedures and regulations,
- (f) Notification of proper personnel regarding safety matters,
- (g) Adherence to safety requirements on the NASA aircraft, and
- (h) Adherence to site safety requirements (e.g. hard hats, high voltage equipment, environmental hazards, etc.).

"Safety consciousness" is each individual's responsibility at all times, not just the responsibility of the Safety Officers.

Selected site and contractor personnel have been trained in areas of first aid, CPR, safety inspections and the proper use of special safety equipment. At least one person who is qualified to administer first aid will be physically present at the test site at all times.

7.12.4.2 NASA B-757 Safety

The NASA aircraft is a fully operational Boeing 757-200 aircraft. After the aircraft is towed, parked and properly oriented on the LESLI pad, it will be inspected by the Ground Crew Chief to ensure that it is properly and safely positioned. Personnel working on the NASA aircraft will adhere to NASA aircraft safety procedures. All personnel will be briefed on aircraft specific safety issues by the NASA aircraft Ground Crew Chief prior to work on or around the aircraft. The aircraft will be grounded at all times except when testing is being performed. The aircraft will be grounded prior to the entry or egress of personnel prior to or after RF illumination. A 150 lb power bottle aviation-type fire extinguisher on the pad satisfies NASA safety requirements for fire hazards.

7.12.4.3 Test Unique Operations

Operating procedures have been established at the EM test sites in the following areas: operations and maintenance, protective equipment, housekeeping, lighting and general safety practices. Under general safety practices there are restrictions concerning clothing, jewelry, intoxicants, tampering with equipment, personal conduct, electrical repairs, railings and toe boards, and the use and storage of hazardous material and equipment. Aircraft maintenance and test support personnel will comply with all safety requirements. It is the responsibility of the Facility Test Director to inform or to designate others to inform NASA, LLNL, or other visitors regarding these practices.

7.12.5 Emergency Procedures

If an emergency situation exists, all test activities will cease and the proper emergency personnel shall be contacted. All personnel will be briefed on access to emergency services.

7.12.5.1 Medical Services

The USAF Hospital at Kirtland AFB will provide emergency assistance and ambulance services for all on-site personnel.

7.12.5.2 Fire Protection

The 377 ABW will provide fire protection services on an on-call basis. It is not expected that any on-site support will be required. Portable fire extinguishers will be required at the aircraft at all times. A 150 lb power bottle aviation-type fire extinguisher on the pad will be required. Small portable fire-extinguishers will be located in trailers and office buildings for office/equipment fires.

7.12.5.3 Accident Reporting

Property and equipment damage, and personnel injury accident reporting procedures required by the Federal and State Governments, by the Government and its participating contractors and subcontractors/vendors will be complied with. Table 7.12-1 lists the personnel to be notified in case of any emergency or safety hazard.

7.12.6 Safety Summary

The Facility Safety Program consists of five major elements:

(a) The designation of a safety team with complete safety authority on the test site,

(b) The establishment and implementation of safety procedures for normal site operations, test preparation and testing operations,

(c) The acquisition and training for the proper utilization of required safety equipment. These include First Aid equipment, personal safety equipment, and any special safety equipment as may be required to minimize potential accidents,

(d) Personnel briefings stressing day-to-day safety practices, and specialized training for designated personnel in the areas of first aid and other safety matters, and

(e) The establishment and implementation of emergency procedures.

7.13 Security

No classified documentation, equipment, or data will be handled during this test. Therefore accounting and control procedures for classified information are not required. There will, however, be base, facility, and test aircraft access and physical security requirements.

7.13.1 Classified Information and Equipment

No classified documentation, equipment, or data will be handled during this test.

7.13.2 Base and Test Site Access

7.13.2.1 Base Access

Kirtland AFB is a controlled access Air Force facility. In general, personnel entering base premises are required to show a vehicle entry pass. Contractors who routinely require access should follow the procedures in their On-Base Security Agreement for the issuance of entry passes.

7.13.2.2 Test Site Access

During test operations, the test site will be unrestricted to personnel who have base access. Appropriate signs will be displayed to require visitors to report to a central location at each test site. A roster of authorized personnel will be provided to all test participants at the start of the test. All test personnel will be charged with challenging individuals who are unfamiliar and are not on the roster. During off-testing hours, the test site will be locked and site security will be ensured by base security police within their normal patrolling routes.

7.13.3 NASA Aircraft Access

During test operations, access to the aircraft may be controlled by Aircraft Operations. Access will be permitted only to personnel who have been approved by Aircraft Operations or who are escorted by a person with escort authorization. During off-testing hours, the aircraft doors will be closed and the stairs and test stands may be pulled away from the aircraft. At the discretion of Aircraft Operations, the stairs and stands may be chained together to prevent unauthorized movement.

7.14 Add-on Tests

As time permits and necessity dictates, additional tests may be added to the program. At present, two major test have been indicated as needed for completeness.

7.14.1 Pad Characterization

As has already been mentioned, an electromagnetic characterization of the pad will be required. Specifically, the constitutive parameters of the pad must be measured to permit modelers to include the ground in simulations. Since the parameters are unknown, and the concrete/aggregate/rebar/soil is not precisely describable, a measurement of the parameters is needed. Since it is expected that the ground is inhomogeneous, a measurement scheme returning parameters averaged over a spatial extent will be made. These measurements will be made without the NASA 757.

To execute the tests, a long wire (the rhombic wire) will be spported a fixed height above the concrete pad on a styrofoam support strip and will be extended across the pad to the full extent of the wire. The height will be chosen to be as small as possible but consistent with the thicknesses of commercially available styrofoam panels. At this time the height is expected to be between 1/4 and 3/4 inches. The wire will be driven against the aluminum source-region ground screen at the rhombic feed point. The wire will be extended in two separate directions (Cases 1 and 2) since the ground plane may be inhomogeneous with constitutive parameter variation as a function of angle with respect to the original rhombic axis. Overhead and cross sectional views of the wire placement are shown in Figures 7.14-1 and 7.14-2.

The wire will be driven against the aluminum plane and the current distribution will be measured by probing with an Prodyn I-320 current probe. The current will be probed at specified points along the wire so that estimates can be made of the attenuation and phase constants of the wave propagating along the wire. From this information, it is expected that the conductivity and permittivity of the pad can be extracted using the theory presented by Chang, Olsen and Kuester [7,8,9]. The test matrix for the pad characterization is presented in Table C-23.

7.14.2 Horizontal Polarization Near Lowest Order Resonances

A set of measurements at frequencies in the vicinity of the first body resonance of the B-757 has been suggested. Since the resonant wavelength for the fuselage is in the vicinity of 94 meters, the resonant frequency is approximately 3.2 MHz. The lowest order resonance associated with the wings falls above 4 MHz while resonances associated with combinations of the wings and fuselage fall above 3.7 MHz. To make such measurements under horizontal polarization, it is expected that the LESLI rhombic will be used in its differential mode rather than attempting to use a $\lambda/2$ dipole since a 47 meter dipole might be mechanically difficult to handle. A balun will be used at the rhombic feed point to ensure push-pull operation so that a horizontally polarized field can be generated. Due to the lack of a reliable broadband balun covering 0.3 to 1000 MHz and questionable quality of the horizontal field, this was not included in the extensive set of rhombic measurements. Nonetheless, given the advisability of having horizontal drive and the inability to efficiently deal with a dipole at the 94 meter wavelength, it was decided to use a balun able to deal with a band possibly covering the lowest order resonances of the aircraft. A balun available to radio amateurs and advertised for 3.5 to 30 MHz will be used and an attempt will be made to reach 3.2 MHz. The airplane will driven in its broadside configuration and measurements will be made at select test points. The decision as to which test points will be recorded will have to include factors such as priority and time available. The test matrix for this horizontal polarization test is provided in Table C-24.

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[7] Chang, D. C. and Olsen, R. G., "Excitation of an Infinite Antenna Above a Dissipative Earth," Radio Science, Volume 10, No8,9, pp. 823-831, August-September, 1975.

[8] Kuester, E. F. , Chang, D. C. and Olsen, R. G. , " Modal Theory of Long Horizontal Wire Structures Above the Earth, 2, Properties of Discrete Modes", Radio Science, Vol 13, No. 4, pp 615-623, July-August 1978.

[9] Olsen, R. G. , Kuester, E. F. and Chang, D. C. , Modal Theory of Long Horizontal Wire Structures Above the Earth, 1, Excitation", Radio Science, Vol. 13, No. 4, pp. 605-613, July-August 1978.

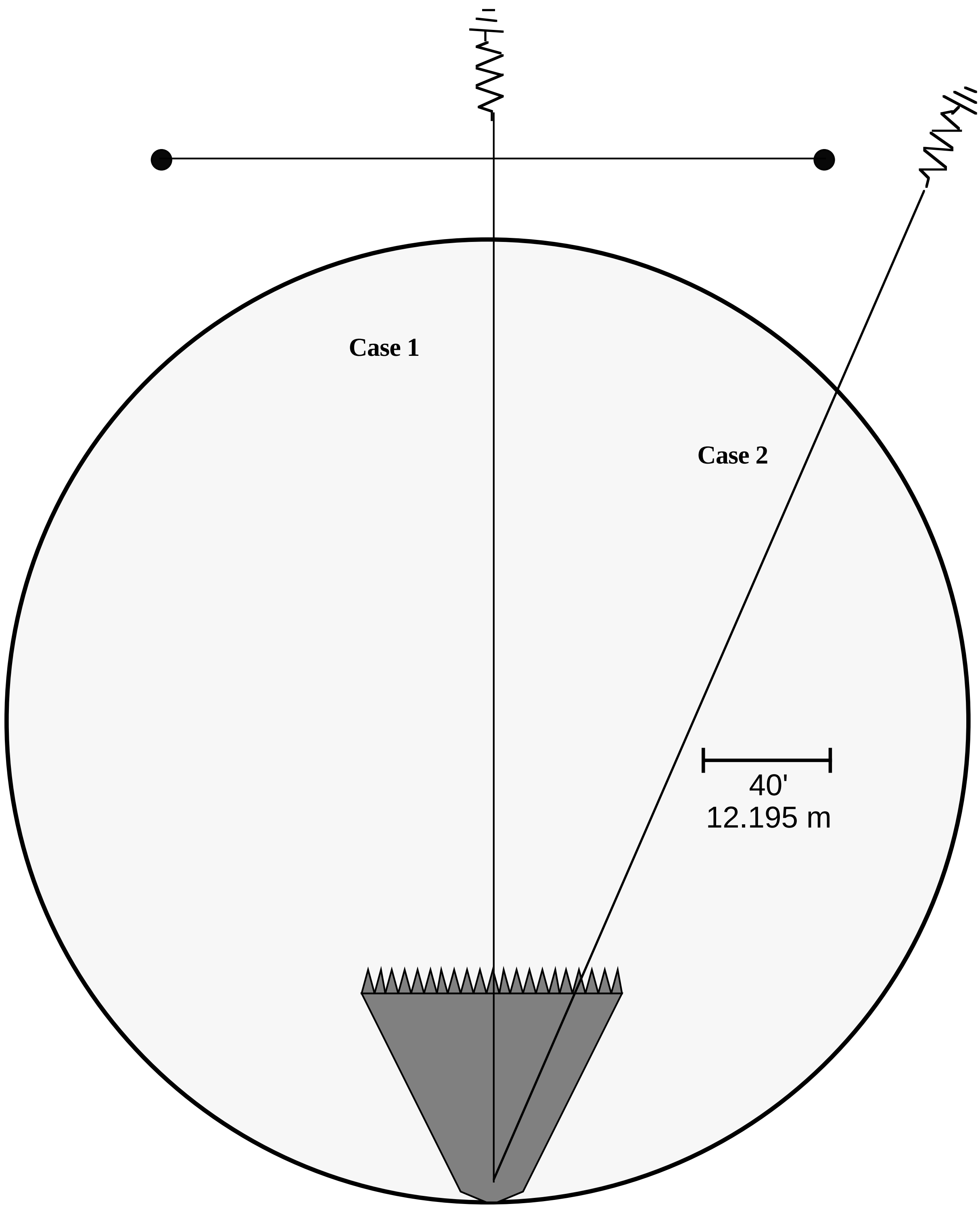

Figure 7.14-1 Pad Characterization Wire Layout for Two Cases

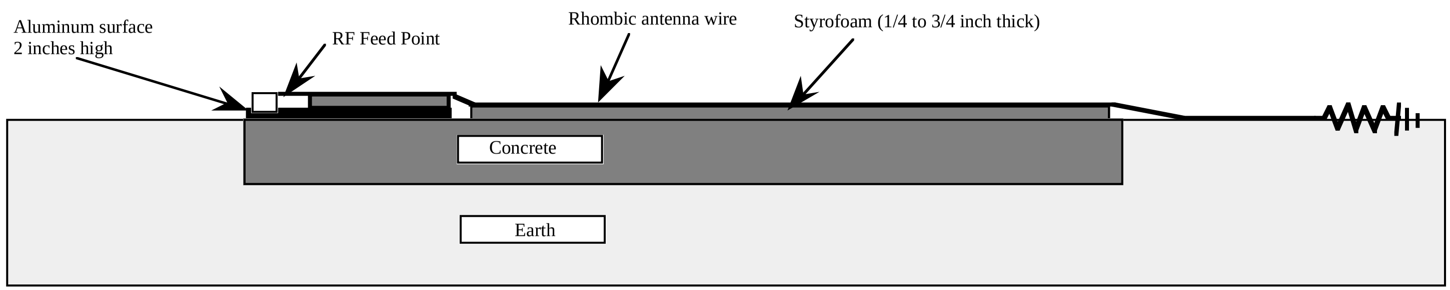

Figure 7.14-2 Pad Characterization Wire Layout - Cross Sectional View

Appendix A   Plane Wave On-the-Ground Test Technical Objectives

In this section we discuss some specific technical objectives of the on-the-ground low-level tests.

A primary objective of the tests is the collection of data for use in the validation of codes that are employed in the modeling of electromagnetic environment in aircraft and its effects on aircraft-borne electronic systems. Of particular interest at this time is the validation of FDTD modeling of coupling into the airframe using a code such as TSAR. The data are also intended for inclusion in a library for use in validation exercises involving modeling tools based on the broad range of techniques and algorithms that are either presently available, in development or otherwise.

The term validation is used to denote the determination whether a particular code is capable of producing accurate results for specific modeling assessments in which it has been applied. Clearly, this will "validate" the physics kernel of the code, its numerical algorithms, and its overall ability to provide the "right" answer. In this particular program, the codes will be tested extensively in their "intended" range where approximations other than discretization are not required (perhaps up to hundreds of MHz) as well as in the range where approximations and special algorithms will be required to estimate stress. While a description of the approximations used to extend the domain of applicability of the code is beyond the scope of this plan, adequate attention has been paid to collecting appropriate data to allow for its use in future validation activities.

During the course of collecting data for the validation exercise, we will also collect data to help us deal with some issues related to modeling, the impact of resolution or "graininess" in the model, random effects, repeatability, and robustness of the measured results. The following, while not totally inclusive, are some of these issues. Note that scheduling constraints may preclude some of the tests.

A.1 Body Resonance. A concern is whether the computer models can accurately account for coupling into the airframe at low frequencies, especially when the external airframe is in body resonance. At these low frequencies, the wavelength is very long with respect to windows and other apertures so that the major coupling path to the interior would likely be through wires or structures that electrically penetrate the airframe or through evanescent wave pickup onto wires or structures near apertures. The degree of coupling may depend heavily on small or seemingly-innocuous features that could easily be missed in converting the physical structure into a computer model. Since we are emphasizing the FDTD model technique for low frequency coupling prediction, it is important that this capability be validated. This can be done by comparing predicted and measured field coupling at interior points in the airframe.

A.2 Thin Wires. Once the EM energy penetrates the airframe, it couples onto the wires and cables that connect the LRUs. (Even fiber-optically interfaced LRUs will have power cables that will pick up energy.) The basic FDTD technique would have difficulty modeling these cables because they are very thin with respect to the resolution element of the computer model. To overcome this problem, special algorithms have been developed that allow thin wires to be modeled. The performance of these algorithms has been validated in simpler geometries and will now be validated in an aircraft environment. This can be done by comparing predicted and measured bulk cable current coupling. Since the only interconnect cables in the FBL/PBW aircraft will be power cables (that are isolated from the airframe), the measurement and simulation will choose a cable that simulates the expected configuration - even if it has to be a dummy cable. This cable should have the correct type of bulkhead feedthrough and the correct type of airframe bonding, if any.

A.3 Thin Slots. Another feature that the basic FDTD model must often treat in a special way is a thin slot. Thin slots are analogous to thin wires - they require special algorithms. In the Boeing 757-200 test object, we feel that the coupling through windows will dominate and that coupling through thin slots such as door frame and hatch frame cracks will be negligible by comparison. However, this assertion, while very likely to be true for the test points of interest during these tests, should be validated. This can be checked by comparing coupling measurement with a suspected door frame or other thin slot initially open and then sealed with metallized tape. If the internal coupling doesn't change, the slot aperture coupling was negligible. The measurement should also be repeated with the door open, because if the door does not make good electrical contact around its perimeter, the coupling would be similar at resonant frequencies to that of an open door.

A.4 FDTD Resolution and the Effect of Randomly Located Features. When the airframe is modeled for the FDTD analysis, a resolution element is selected based on a combination of issues including the wavelength at the highest frequency of interest, the detail desired in the model, and/or the computer resources available. Metallic and dielectric structures that are small with respect to the size of the resolution element may be ignored. Some internal objects such as the crew, passengers, carry-on luggage, and other moveable cargo may be large, but their instantaneous positions cannot be described deterministically. The positions of "fixed" objects may vary from aircraft to aircraft over the fleet ensemble, so their positions must also be considered as randomly placed. In the computer model, these variations are either ignored or are described with representative structures in the model. The aggregate effect that these omitted or approximated structures have on coupling may be significant. It is important that the magnitude of the effect that these omitted or approximated features have on coupling be understood. In order to get an approximate estimate of the effect of these features a few measurements will be made where realistic representations of such objects of various sizes are moved around in random positions, or with someone in the cockpit to represent the pilot. The variations we see in these measured data will provide insight as to how accurately we can ever expect the predictions to approach reality.

A.5 Cockpit Window. The cockpit window is expected to be a significant coupling apertuse. However, this window is usually coated with an electrically conducting film that is connected by cable to a power supply to allow it to be heated for deicing. Therefore, the coupling through this aperture will depend strongly upon how this film is electrocally bonded to thg surrounding metal surface, if it is at all. If there is no bonding to the akrframe, this window might act like a large patch antenna, admitting frequencies above and below the aperture resonance that would be expected for an open window of the same size. If the film is bonded to the airframe in one location, the window would still accept frequencies only above its aperture resonancg. If the film is electrically opaque to the wave, then a thin slot algorithm may be required to describe it. We must validate that the model we use to represent this window is accurate. We can isolate the coupling through the window by making a measurement with the window open and then repeating it with the window sealed with metallic foil and tape. These measurements would allow us to investigate the computer model of the window. Similar data has been taken by the Phillips Laboratory that will provide a qualitative insight to cockpit coupling. This reduces the priority for this measurement. This low priority test will be placed at the end of the test schedule. Due to the compressed test schedule, this test will not likely occur.

A.6 Angular Sensitivity. When flight tests are ultimately made, the exact orientation of the aircraft at the time that the EME signal measurement is made will be estimated using on-board systems. There will be some error in these estimates. It is important to know how sensitive the measurements of coupling are to small changes in pitch, roll, and yaw. In the on-the-ground coupling tests, varying pitch and roll may be difficult. However, it is simple to vary yaw. Therefore, a series of measurements will be made with small changes in ˘aw in order to quantify the error such warkations will have in coupling.

A.7 Measurement Repeatability. Measurement repeatability is an issue similar to angular variation. We can never expect to validate to an accuracy better than the random measurement error. To test this error, measurements of coupling into the airframe for a few select configurations and orientations will be repeated several times over the testing period.

A.8 Effects of the Earth. One potential source of modeling error associated with on-the-ground tests that is not found in airborne tests is the effect of conductivity and dispersion in the soil or concrete upon which the aircraft sits. These values will change with the moisture content of the soil or pad.

Appendix B Power Densities and Field Strengths for Aircraft Tests

LESLI Rhombic Tests

The aircraft will be manned during several tests, namely, during the fly-by instrumentation tests and during some tests which call for evaluation of sensitivity of the results to personnel deployment. The field strengths or power density in such tests must be below the levels which represent a hazard to humans. The IEEE C95.1-1991 / DoDI 6055.11 (Draft) standard for maximum permissible field exposure for personnel in a controlled environment is 1 mW/cm^2 over the frequency range from 300 KHz to 1 GHz. This corresponds to an electric field strength of 61.4 V/m for a plane wave field in free space. Neither LLNL, NASA, PL, or the older ANSI standard C95.1-1982 have exposure limits below 1 mW/cm^2 over any frequency band. Hence field levels below this level can be considered innocuous to humans.

Concern is also expressed for the safety of on-board equipment. While the vulnerability levels of this gear is not known at this time, field levels estimated below will allow the safety assessment to be performed.

The field within the LESLI rhombic, while not precisely describable by a transmission line model, has been approximately modeled in such a manner. [10,11] The results have been found to be adequate in trials against experimental results. The following are some results from this analysis.

In a coordinate system with z along the axis of the rhombic, x transverse and along the ground plane, and y oriented perpendicular to the ground (see Fig 7.4-1 for help in this visualization)

$$E_y = \mathrm{Sqrt}[1.87\ W/(\pi\ Z_c/Z_o)]\ (1/b)\ [\exp(-j\omega r/c)]\ f_{cm}(z,y)$$

$$E_z = \mathrm{Sqrt}[1.87\ W/(\pi\ Z_c/Z_o)]\ (1/b)\ [\exp(-j\omega r/c)]\ g_{cm}(z,y)$$

where

$$f_{cm} = b\ (y-b) / [(z-a)^2+(y-b)^2] + b\ (y-b) / [(z+a)^2+(y-b)^2] \\ -b\ (y+b) / [(z-a)^2+(y+b)^2] - b\ (y+b) / [(z+a)^2+(y+b)^2]$$

$$g_{cm} = b\ (z-a) / [(z-a)^2+(y-b)^2] + b\ (z+a) / [(z+a)^2+(y-b)^2] \\ -b\ (z-a) / [(z-a)^2+(y+b)^2] - b\ (z+a) / [(z+a)^2+(y+b)^2]$$

$$Z_c = \ln[[1+(1+(R/b)^2)^{1/2}-R/b] / [1-(1+(R/b)^2)^{1/2}+R/b]]/(4\ \pi) + \ln[1+(b/a)^2]/(8\pi)$$

Z_o = 377 Ohms
W = Input Power
l = distance from source to max height of rhombic
a = distance of wire from centerline at any x
b = height of wire from ground at any x
R = wire radius
r = distance from source

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[10] Kehere, W. S.,Atchley, L., Engheta, N., Marin, L., Martinez, J. P., "Results of the Initial Field Mapping of the AFWL Hardness Surveillance Illuminator", Kaman Sciences Corp Report DC-TR-4088.430-2, January 1987.

[11] Darras, D., Zuffada, C., Marin, L., Atchley, L., "Theory of Operation of Achilles III and Performance Evaluation", Achilles Memos: Memo 11, AFWL.

Using these expressions, fields were calculated for points within the test volume. The specific quantities used were:

W = 100 watts (radiated power)
l = 100 m
a(maximum) = 16 m
b(maximum) = 26 m
R = 0.002 m

The ranges of the parameters in the figures were chosen to approximately cover the spatial extent of the airplane and the intended test volume. The airplane will be located at least 40 meters from the source. Its fuselage radius is approximately 4.5 meters and its wingspan approximately 38 meters. Its fuselage height is less than 6.5 meters.

Figure B-1 shows the principal electric field (the y component) for z between 35 and 70 meters and x from 0 to 20 meters at the ground plane. The field never exceeds 3 V/m.

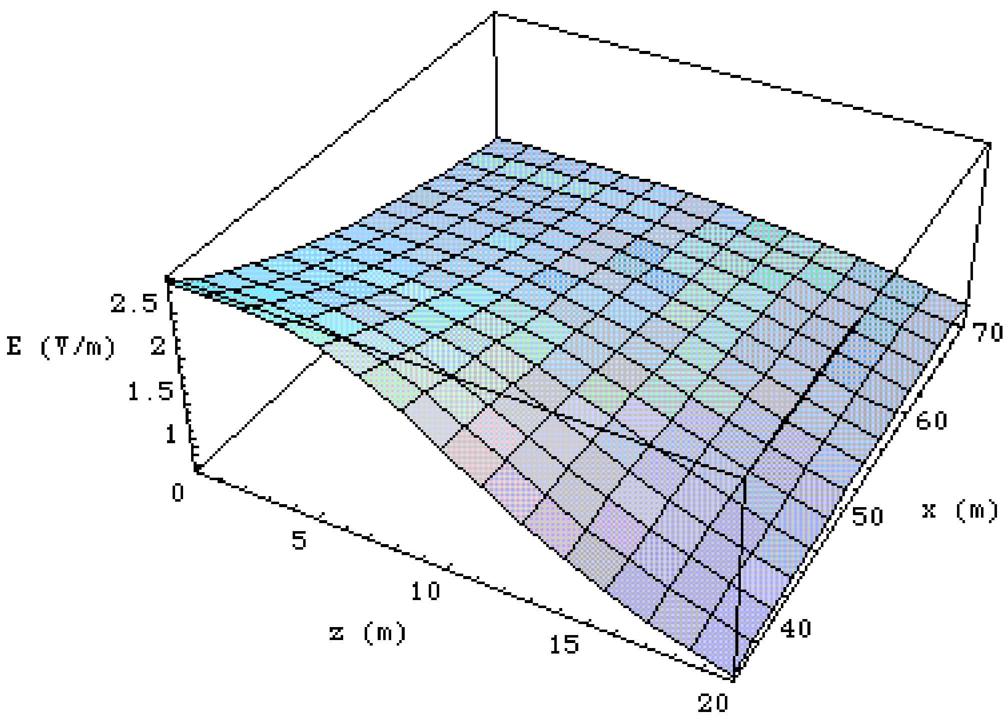

Fig B-1. Principal Electric Field at y=0

The corresponding electric field in the transverse plane (x-y plane) at z=40 meters is shown in Fig B-2. The peaking taking place near y = 4 meters is due to proximity to the rhombic wire. Figure B-3 shows the same field component over a greater range of height and transverse position.

The cross polarized components of the field (the x-directed component) is also of concern. Physics requires this component to be zero along the ground plane (for a perfect conductor) and symmetry requires it to be zero along the x = 0 plane. Figure B-4 shows this transverse field in the transverse plane at z = 40 meters. At heights less than 5 meters the field is less than 1 V/m..

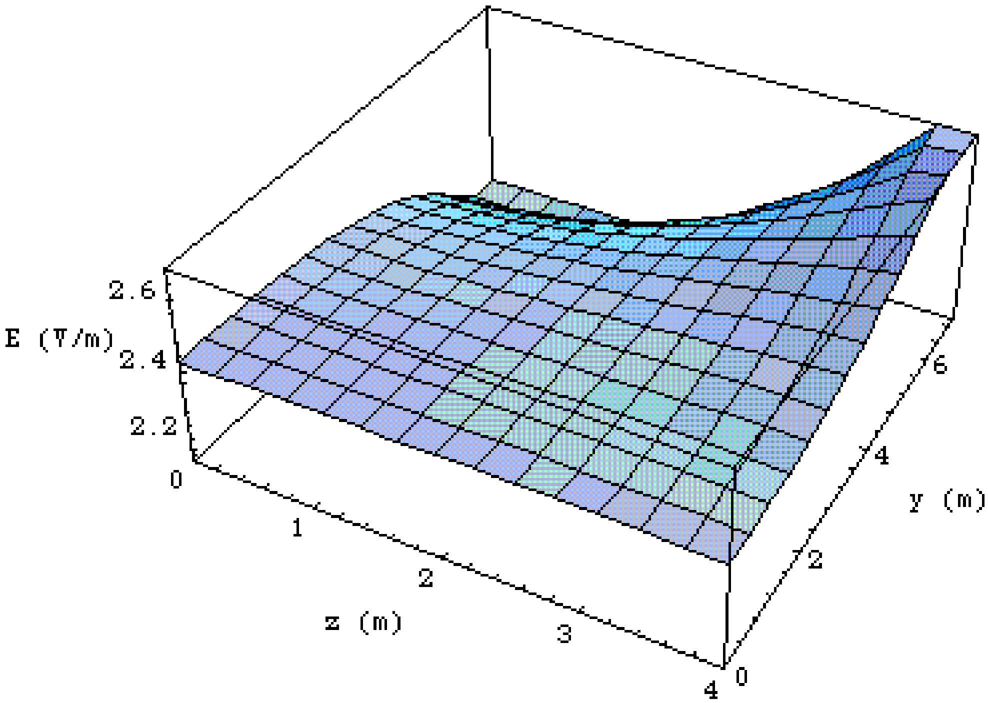

Figure B-2. Principal Electric Field at x = 40 meters, y less than 7 meters

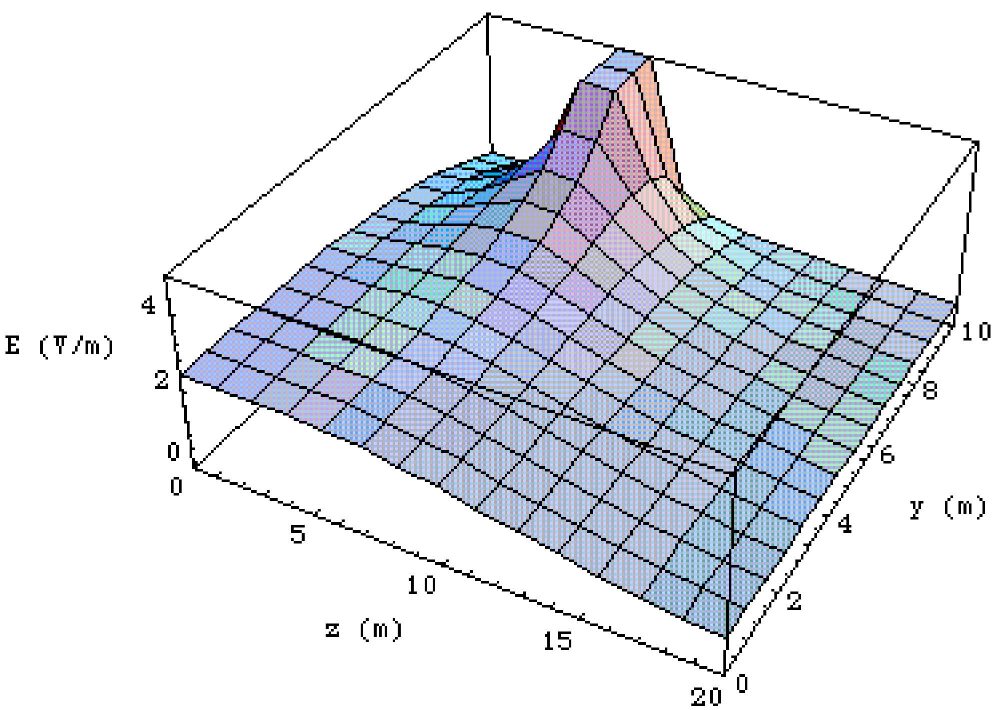

Figure B-3. Principal Electric Field at x = 40 meters, y less than 10 meters

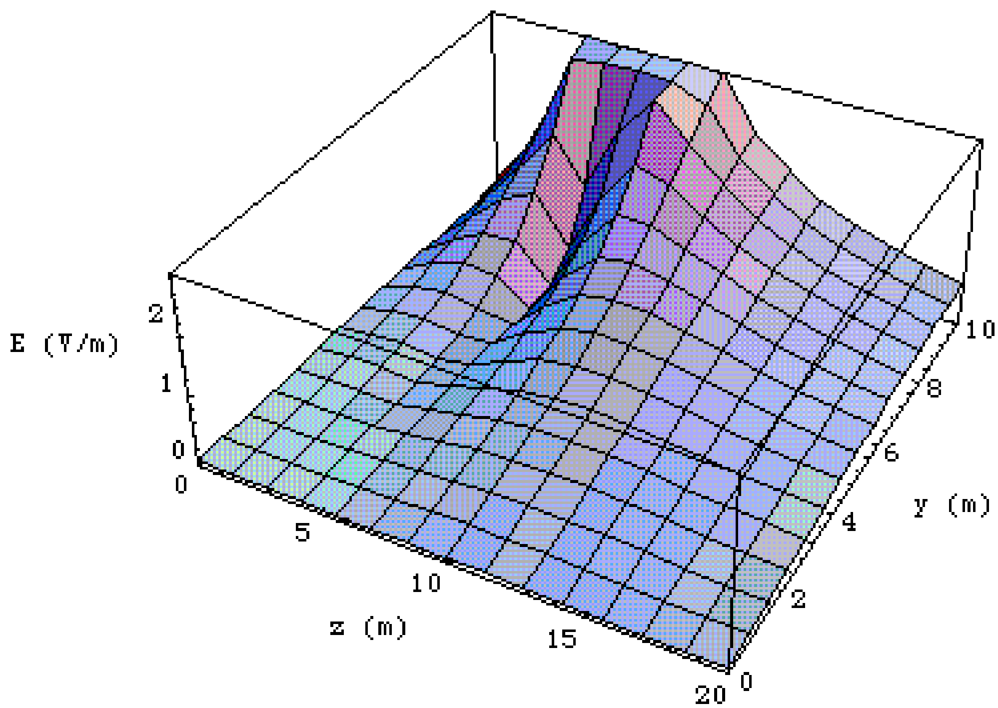

Figure B-4. Transverse electric field at x = 40 meters

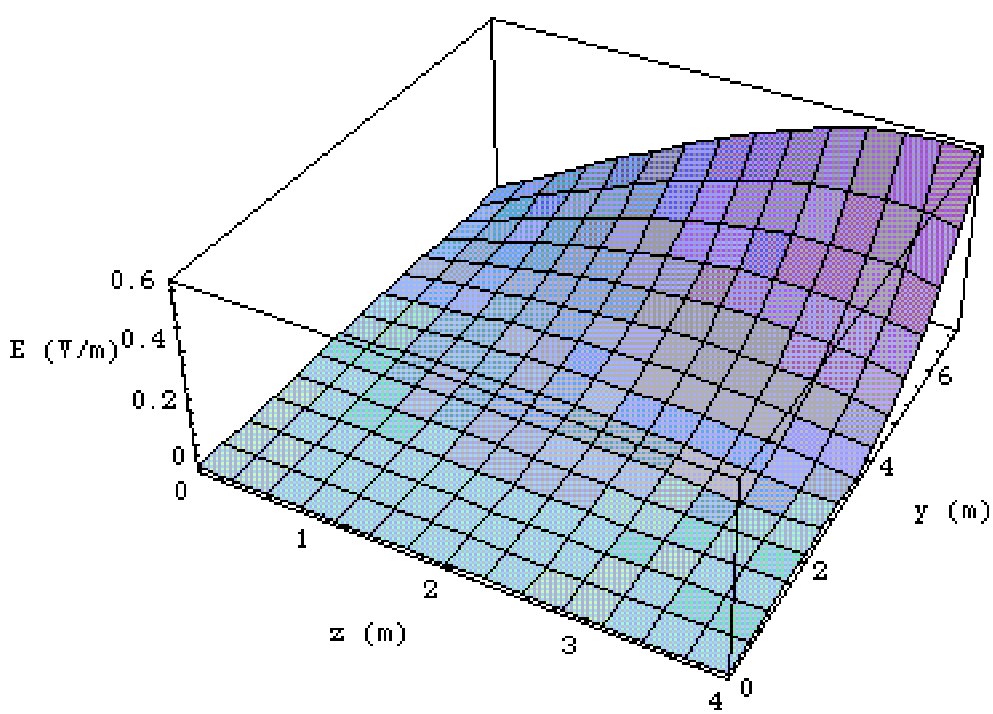

Figure B-5. Transverse electric field at x=40 m, z<4 m, y<7 m

The field levels at the location of the airplane without its presence is thus below 5 volts per meter over the extent of the fuselage. This statement is true for either nose on or broadside incidence with the airplane in the positions shown in Figures 7.4-2 and 7.4-3. The equivalent power density is less than 0.007 mW/cm^2. Even allowing for inaccuracy in the model, this is well below the personnel safety standard by almost an order of magnitude in field[12]. Shielding provided by the aircraft will, of course, reduce the field levels.

Dipole Tests

The dipole tests will be performed with the dipole located at a point forward of the wing and outboard of the fuselage. Closest approach to the airplane is 10 meters. The dipoles will be very close to their half-wave resonances in the tests.
For horizontal polarization, the dipoles will be at a distance above the ground plane.

The incident power density in the direction of maximum gain is given by

$$S = \text{Gain} \times \text{Power Input} / (4 \pi R^2)$$

For a dipole in free space with gain of 1.64 (2.15 dBi), a range of 5 meters, and a power input of 1 watt, the incident power density at the axis airplane is 0.0052 W/m^2 with the attendant electric field of 1.4 V/m. For a dipole over a ground plane, the peak gain can be twice as high as free space with peak incident power density of 0.021 W/m^2 and attendant electric field of 2.8 V/m. Hence, for a dipole over ground radiating 100 watts, the peak power density at 5 meters would be 2.1 W/m^2 and the peak electric field would be 28 V/m. These estimates are below safety thresholds.

[12] Further confidence in personnel safety is provided by measurements made within the facility. During the F-16 Pre Test Field Measurements in the LESLI facility, UIE reported on the field levels at various points on the test pad. For full-level, output power from the RF amps driving the rhombic with 100 watts, peak power density did not exceed 0.16 mW/cm*cm at a point 10m from the feed on the centerline of the rhombic. ("Report of High Frequency Research Facility F-16 Pre-Test Field Measurements" United International Engineering, Inc., UIE-TR-92-0010, 22 June 1992.

Appendix C On-the-Ground Test Matrix

This section contains an estimate of the time required to complete the test sequence for the on-the-ground tests and a test matrix for low-power tests. These estimates are found in Tables C-1 through C-8.

The test matrix is presented in Tables C-9 though C-21. Test Series A through F correspond to the dipole tests described in Section 7.7. Test Series G through I correspond to the on-board instrumentation tests described in Section 7.8. Tests Series J and K correspond to the stepped frequency rhombic tests described in Section 7.9. Each table contains the configurations, orientations, and test points for a test series with a given polarization and frequency band. Antenna configurations and/or instrumentation systems will be changed for each test series. This matrix also indicates a preferred order for the tests. The test will proceed such that the most time-consuming changes (such as moving the aircraft) occur less frequently, at the expense of making the less time-consuming changes (such as swapping probe locations) more often.

In all cases, the frequency ranges shown are the likely minimum. The ranges will be extended to include as much of the frequency range around the center frequency as possible

Table C-1. Pre-aircraft field time at PL

Set up data acquisition format, run-number code, etc.	1 day
Set up data acquisition instrumentation, antennas in required locations and check out equipment. Dry run tests.	5. days
Tests to assure FAA compatibility	2. days
Field map survey for Test Series J, K	10. days
Total pre-aircraft field time at PL	18 days @ 8 hrs/day

Table C-2. Test Series A - F (three frequencies, vertical and horizontal dipoles, aircraft nose-incident orientation on ground plane)

Fly In to ABQ, Aircraft Operations activities	1 day
Install non-flightworthy items, switch cable connections, cal cables	1 day
Position aircraft	2.5 hrs
Hook up instrumentation, fibers	1.5 hrs
RC-7 replaces installed NASA aircraft transceiver	1 hr
Initial tests - dynamic range, noise floor 12 tests	1 day
26 MHz, vertical whip stepped measurements, setup, 12 tests:	1 day
26 MHz, horizontal dipole stepped measurements, setup, 12 tests	1 day
172 MHz, vertical dipole stepped measurements, setup, 12 tests	1 day
172 MHz, horizontal dipole stepped measurements, setup, 12 tests	1 day
430 MHz, vertical dipole stepped measurements, setup, 12 tests	1 day
430 MHz, horizontal dipole stepped measurements, setup, 12 tests	1 day
Slack	4 hrs
Total	10 days @ 10 hr/day

Table C-3 Test Series G, H, I
(On-board instrumentation check-out, rhombic, vertical, aircraft nose-incident)

Hook up sensors to on-board instrumentation,	
Remove RC-7 box and install NASA aircraft transceiver	1 hr
Power up aircraft and instrumentation	1 hr
Tests at 25.85 MHz, Debug, exercise equipment	2 hrs
Tests at 172.0 MHz, Debug, exercise equipment	4 hrs
Tests at 430.0 MHz, Debug, exercise equipment	4 hrs
Slack (large slack time to accommodate potential problems)	4 hrs
Reconnect sensors to fibers for stepped frequency tests, install RC-7 box	5 hrs
Install Rhombic Antenna	10 hrs
	4 hrs
Total	3.5 days @ 10 hr/day

Table C-4 Test Series J (0.3 - 1000 MHz, vertical, nose incident)

Reposition aircraft, 5°	1.5 hrs
Reposition aircraft, 2° or 10°	1.5 hrs
Stepped measurements, 41 Tests	37 hrs
Total	4.0 days @ 10 hr/day

Table C-5 Test Series K (0.3 - 1000 MHz, vertical, side incident)

Reposition aircraft to 90°	1.5 hrs
Stepped measurements, 30 tests	37 hrs
Remove fibers, RC-7 box, etc.	1.5 hrs
Total	4.0 days @ 10 hr/day

Table C-6 Post-Test Aircraft Time

Return aircraft to flightworthy state, QA inspection	2 day
Roll out aircraft, return to airport, fly out to LaRC	1 day
Total post-test aircraft time	3 days @ 10 hrs/day

Total aircraft test time **21.5 days @ 10 hr./ day**

Table C-7 Post Aircraft Decommission

Clean up	2 days
Total post-aircraft field time	2 days @ 8 hrs/day

Table C-8 Total Time Allocations

Total Pre-Aircraft Field Time at PL	18 days @ 8 hrs/day
Test Series A-F	10 days @ 10 hr/day
Test Series G, H, I	3.0 days (up to 10 hr/day)
Test Series J	4.0 days @ 10 hr/days
Test Series K	4.0 days @ 10 hr/day
Post-Test Aircraft Time	3.0 days @ 8 hrs/day
Post Aircraft Decommission	2 days @ 8 hrs/day

Table C-9. Ambient Noise Measurements

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Configuration	Notes
AN1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000				U
AN2	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000				U
AN3	EB3	E-bay	Cable Current	I-320 Probe	0.3 - 1000				U
AN4	C4	Cabin	Field	Ext. antenna	0.3 - 1000				U

• **Notes: This measurement set will investigate or validate:**
U) Ambient noise measurement

Table C-10. Test Series A

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Configuration	Notes
A1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	23 - 28	Dipole	H	Dipole // to a/c axis	A
A2	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	23 - 28	Dipole	H	Dipole // to a/c axis	A
A3	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	23 - 28	Dipole	H	Dipole // to a/c axis	A
A4	CP4	Cockpit	Wire Current	I-320 Probe	23 - 28	Dipole	H	Dipole // to a/c axis	B
A5	CP5	Cockpit	Wire Voltage	climbing wire	23 - 28	Dipole	H	Dipole // to a/c axis	B
A6	EB1	E-bay	Field	AD-60 D-Dot	23 - 28	Dipole	H	Dipole // to a/c axis	A
A7	EB2	E-bay	LRU Voltage	Voltage Probe	23 - 28	Dipole	H	Dipole // to a/c axis	D
A8	EB3	E-bay	Cable Current	I-320 Probe	23 - 28	Dipole	H	Dipole // to a/c axis	B
A9	C1	Cabin	Field	AD-60 D-Dot	23 - 28	Dipole	H	Dipole // to a/c axis	A
A10	C2	Cabin	Wire Current	I-320 Probe	23 - 28	Dipole	H	Dipole // to a/c axis	B
A11	C3	Cabin	Voltage	Long Wire	23 - 28	Dipole	H	Dipole // to a/c axis	B
A12	C4	Cabin	Field	Ext. antenna	23 - 28	Dipole	H	Dipole // to a/c axis *	C
A13	Weak Signal Line				23 - 28	Dipole	H	Dipole // to a/c axis	V
A14	Strong Signal Line				23 - 28	Dipole	H	Dipole // to a/c axis	V

• **Notes: This measurement set will investigate or validate:**
A) FDTD predictions of field coupling; transmit antenna in computational volume
B) FDTD predictions of thin wire coupling; transmit antenna in computational volume
C) Calibration of aircraft external field measurement
D) Typical coupling into a representative critical LRU in the E-bay
V) Dipole Instrumentation Noise Measurements: Strongest and Weakest channels observed over the test series are chosen. Probe is replaced by matched load and noise signals recorded.
* Lower priority, skip if short of time

Table C-11. Test Series B

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Config.	Notes
B1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	23 - 28	Dipole	V	front, left of a/c	A
B2	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	23 - 28	Dipole	V	front, left of a/c	A
B3	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	23 - 28	Dipole	V	front, left of a/c	A
B4	CP4	Cockpit	Wire Current	I-320 Probe	23 - 28	Dipole	V	front, left of a/c	B
B5	CP5	Cockpit	Wire Holtage	climbing wire	23 - 28	Dipole	V	front, left of a/c	B
B6	EB1	E-bay	Field	AD-60 D-Dot	23 - 28	Dipole	V	front, left of a/c	A
B7	EB2	E-bay	LRU Voltage	Voltage Probe	23 - 28	Dipole	V	front, left of a/c	D
B8	EB3	E-bay	Cable Current	I-320 Probe	23 - 28	Dipole	V	front, left of a/c	B
B9	C1	Cabin	Field	AD-60 D-Dot	23 - 28	Dipole	V	front, left of a/c	A
B10	C2	Cabin	Wire Current	I-320 Probe	23 - 28	Dipole	V	front, left of a/c	B
B11	C3	Cabin	Voltage	Long Wire	23 - 28	Dipole	V	front, left of a/c	B
B12	C4	Cabin	Field	Ext. antenna	23 - 28	Dipole	V	front, left of a/c *	C
B13	C1	Cabin	Field	AD-60 D-Dot	25.7 - 26	Dipole	V	1% BW, 1000 pts	E
B14	Weak Signal Line				23 - 28	Dipole	V	front, left of a/c	V
B15	Strong Signal Line				23 - 28	Dipole	V	front, left of a/c	V

- **Notes: This measurement set will investigate or validate:**
  - A) FDTD predictions of field coupling; transmit antenna in computational volume
  - B) FDTD predictions of thin wire coupling; transmit antenna in computational volume
  - C) Calibration of aircraft external field measurement
  - D) Typical coupling into a representative critical LRU in the E-bay
  - E) Variations in coupling with frequency (frequency stirring)
  - V) Dipole Instrumentation Noise Measurements

* Lower priority, skip if short of time

Table C-12. Test Series C

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Config.	Notes
C1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	150 - 200	Dipole	V	front, left of a/c	A
C2	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	150 - 200	Dipole	V	front, left of a/c	A
C3	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	150 - 200	Dipole	V	front, left of a/c	A
C4	CP4	Cockpit	Wire Current	I-320 Probe	150 - 200	Dipole	V	front, left of a/c	B
C5	CP5	Cockpit	Wire Voltage	climbing wire	150 - 200	Dipole	V	front, left of a/c	B
C6	EB1	E-bay	Field	AD-60 D-Dot	150 - 200	Dipole	V	front, left of a/c	A
C7	EB2	E-bay	LRU Voltage	Voltage Probe	150 - 200	Dipole	V	front, left of a/c	D
C8	EB3	E-bay	Cable Current	I-320 Probe	150 - 200	Dipole	V	front, left of a/c	B
C9	C1	Cabin	Field	AD-60 D-Dot	150 - 200	Dipole	V	front, left of a/c	A
C10	C2	Cabin	Wire Current	I-320 Probe	150 - 200	Dipole	V	front, left of a/c	B
C11	C3	Cabin	Voltage	Long Wire	150 - 200	Dipole	V	front, left of a/c	B
C12	C4	Cabin	Field	Ext. antenna	150 - 200	Dipole	V	front, left of a/c *	C
C13	C1	Cabin	Field	AD-60 D-Dot	171 - 173	Dipole	V	1% BW, 1000 pts	E
C14	Weak Signal Line				150 - 200	Dipole	V	front, left of a/c	V
C15	Strong Signal Line				150 - 200	Dipole	V	front, left of a/c	V

- **Notes: This measurement set will investigate or validate:**
  - A) FDTD predictions of field coupling; transmit antenna in computational volume
  - B) FDTD predictions of thin wire coupling; transmit antenna in computational volume
  - C) Calibration of aircraft external field measurement
  - D) Typical coupling into a representative critical LRU in the E-bay
  - E) Variations in coupling with frequency (frequency stirring)
  - V) Dipole Instrumentation Noise Measurements

* Lower priority, skip if short of time

Table C-13. Test Series D

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Config.	Notes
D1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	150 - 200	Dipole	H	Dipole // to a/c axis	A
D2	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	150 - 200	Dipole	H	Dipole // to a/c axis	A
D3	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	150 - 200	Dipole	H	Dipole // to a/c axis	A
D4	CP4	Cockpit	Wire Current	I-320 Probe	150 - 200	Dipole	H	Dipole // to a/c axis	B
D5	CP5	Cockpit	Wire Voltage	climbing wire	150 - 200	Dipole	H	Dipole // to a/c axis	B
D6	EB1	E-bay	Field	AD-60 D-Dot	150 - 200	Dipole	H	Dipole // to a/c axis	A
D7	EB2	E-bay	LRU Voltage	Voltage Probe	150 - 200	Dipole	H	Dipole // to a/c axis	D
D8	EB3	E-bay	Cable Current	I-320 Probe	150 - 200	Dipole	H	Dipole // to a/c axis	B
D9	C1	Cabin	Field	AD-60 D-Dot	150 - 200	Dipole	H	Dipole // to a/c axis	A
D10	C2	Cabin	Wire Current	I-320 Probe	150 - 200	Dipole	H	Dipole // to a/c axis	B
D11	C3	Cabin	Voltage	Long Wire	150 - 200	Dipole	H	Dipole // to a/c axis	B
D12	C4	Cabin	Field	Ext. antenna	150 - 200	Dipole	H	Dipole // to a/c axis*	C
D13	Weak Signal Line				150 - 200	Dipole	H	Dipole // to a/c axis	V
D14	Strong Signal Line				150 - 200	Dipole	H	Dipole // to a/c axis	V

• **Notes: This measurement set will investigate or validate:**

A) FDTD predictions of field coupling; transmit antenna in computational volume
B) FDTD predictions of thin wire coupling; transmit antenna in computational volume
C) Calibration of aircraft external field measurement
D) Typical coupling into a representative critical LRU in the E-bay
V) Dipole Instrumentation Noise Measurements
* Lower priority, skip if short of time

Table C-14. Test Series E

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Config.	Notes
E1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	350 - 500	Dipole	V	front, left of a/c	A
E2	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	350 - 500	Dipole	V	front, left of a/c	A
E3	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	350 - 500	Dipole	V	front, left of a/c	A
E4	CP4	Cockpit	Wire Current	I-320 Probe	350 - 500	Dipole	V	front, left of a/c	B
E5	CP5	Cockpit	Wire Voltage	climbing wire	350 - 500	Dipole	V	front, left of a/c	B
E6	EB1	E-bay	Field	AD-60 D-Dot	350 - 500	Dipole	V	front, left of a/c	A
E7	EB2	E-bay	LRU Voltage	Voltage Probe	350 - 500	Dipole	V	front, left of a/c	D
E8	EB3	E-bay	Cable Current	I-320 Probe	350 - 500	Dipole	V	front, left of a/c	B
E9	C1	Cabin	Field	AD-60 D-Dot	350 - 500	Dipole	V	front, left of a/c	A
E10	C2	Cabin	Wire Current	I-320 Probe	350 - 500	Dipole	V	front, left of a/c	B
E11	C3	Cabin	Voltage	Long Wire	350 - 500	Dipole	V	front, left of a/c	B
E12	C4	Cabin	Field	Ext. antenna	350 - 500	Dipole	V	front, left of a/c *	C
E13	C1	Cabin	Field	AD-60 D-Dot	427 - 432	Dipole	V	1% BW, 1000 pts	E
E14	Weak Signal Line				350 - 500	Dipole	V	front, left of a/c	V
E15	Strong Signal Line				350 - 500	Dipole	V	front, left of a/c	V

• **Notes: This measurement set will investigate or validate:**

A) FDTD predictions of field coupling; transmit antenna in computational volume
B) FDTD predictions of thin wire coupling; transmit antenna in computational volume
C) Calibration of aircraft external field measurement
D) Typical coupling into a representative critical LRU in the E-bay
E) Variations in coupling with frequency (frequency stirring)
V) Dipole Instrumentation Noise Measurements* Lower priority, skip if short of time

Table C-15. Test Series F

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Config.	Notes
F1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	350 - 500	Dipole	H	Dipole // to a/c axis	A
F2	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	350 - 500	Dipole	H	Dipole // to a/c axis	A
F3	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	350 - 500	Dipole	H	Dipole // to a/c axis	A
F4	CP4	Cockpit	Wire Current	I-320 Probe	350 - 500	Dipole	H	Dipole // to a/c axis	B
F5	CP5	Cockpit	Wire Voltage	climbing wire	350 - 500	Dipole	H	Dipole // to a/c axis	B
F6	EB1	E-bay	Field	AD-60 D-Dot	350 - 500	Dipole	H	Dipole // to a/c axis	A
F7	EB2	E-bay	LRU Voltage	Voltage Probe	350 - 500	Dipole	H	Dipole // to a/c axis	D
F8	EB3	E-bay	Cable Current	I-320 Probe	350 - 500	Dipole	H	Dipole // to a/c axis	B
F9	C1	Cabin	Field	AD-60 D-Dot	350 - 500	Dipole	H	Dipole // to a/c axis	A
F10	C2	Cabin	Wire Current	I-320 Probe	350 - 500	Dipole	H	Dipole // to a/c axis	B
F11	C3	Cabin	Voltage	Long Wire	350 - 500	Dipole	H	Dipole // to a/c axis	B
F12	C4	Cabin	Field	Ext. antenna	350 - 500	Dipole	H	Dipole // to a/c axis *	C
F13	Weak Signal Line				350 - 500	Dipole	H	Dipole // to a/c axis	V
F14	Strong Signal Line				350 - 500	Dipole	H	Dipole // to a/c axis	V

• **Notes: This measurement set will investigate or validate:**
A) FDTD predictions of field coupling; transmit antenna in computational volume
B) FDTD predictions of thin wire coupling; transmit antenna in computational volume
C) Calibration of aircraft external field measurement
D) Typical coupling into a representative critical LRU in the E-bay
V) Dipole Instrumentation Noise Measurements: Strongest and Weakest channels observed over the test series are chosen. Probe is replaced by matched load and noise signals recorded.
The frequency range shown is the likely minimum. The range will be extended to include as much of the 350 to 510 MHz range as possible
* Lower priority, skip if short of time

Table C-16. Noise Floor Measurements

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Configuraation	.Notes
NO1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	Nose Incident	T
NO2	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	Nose Incident	T
NO3	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	Nose Incident	T
NO4	CP4	Cockpit	Wire Current	I-320 Probe	0.3 - 1000	Rhombic	V	Nose Incident	T
NO5	CP5	Cockpit	Wire Voltage	climbing wire	0.3 - 1000	Rhombic	V	Nose Incident	T
NO6	EB1	E-bay	Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	Nose Incident	T
NO7	EB2	E-bay	LRU Voltage	Voltage Probe	0.3 - 1000	Rhombic	V	Nose Incident	T
NO8	EB3	E-bay	Cable Current	I-320 Probe	0.3 - 1000	Rhombic	V	Nose Incident	T
NO9	C1	Cabin	Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	Nose Incident	T
NO10	C2	Cabin	Wire Current	I-320 Probg	0.3 - 1000	Rhombic	V	Nose Incident	T
NO11	C3	Cabin	Voltage	Long Wire	0.3 - 1000	Rhombic	V	Nose Incident	T
NO12	C4	Cabin	Field	Ext. antenna	0.3 - 1000	Rhombic	V	Nose Incident	T

• **Notes: This measurement set will investigate or validate:**
T) Measurement noise floors

Table C-17. Test Series G

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Config.	Notes
G1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	25.85	Rhombic	V	a/c nose incident	F
G2	EB1	E-bay	Field	AD-60 D-Dot	25.85	Rhombic	V	a/c nose incident	F
G3	EB3	E-bay	Cable Current	I-320 Probe	25.85	Rhombic	V	a/c nose incident	F
G4	C1	Cabin	Field	AD-60 D-Dot	25.85	Rhombic	V	a/c nose incident	F
G5	C2	Cabin	Wire Current	I-320 Probe	25.85	Rhombic	V	a/c nose incident	F
G6	C3	Cabin	Voltage	Long Wire	25.85	Rhombic	V	a/c nose incident	F
G7	C4	Cabin	Field	Ext. antenna	25.85	Rhombic	V	a/c nose incident	C, F

• **Notes: This measurement set will investigate or validate:**
C) Calibration of aircraft external field measurement
F) On-board instrumentation check-out

Table C-18. Test Series H

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Config.	Notes
H1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	172.0	Rhombic	V	a/c nose incident	F
H2	EB1	E-bay	Field	AD-60 D-Dot	172.0	Rhombic	V	a/c nose incident	F
H3	EB3	E-bay	Cable Current	I-320 Probe	172.0	Rhombic	V	a/c nose incident	F
H4	C1	Cabin	Field	AD-60 D-Dot	172.0	Rhombic	V	a/c nose incident	F
H5	C2	Cabin	Wire Current	I-320 Probe	172.0	Rhombic	V	a/c nose incident	F
H6	C3	Cabin	Voltage	Long Wire	172.0	Rhombic	V	a/c nose incident	F
H7	C4	Cabin	Field	Ext. antenna	172.0	Rhombic	V	a/c nose incident	C, F

• **Notes: This measurement set will investigate or validate:**
C) Calibration of aircraft external field measurement
F) On-board instrumentation check-out

Table C-19. Test Series I

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Config.	Notes
I1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	430 pulsed	Rhombic	V	a/c nose incident	F
I2	EB1	E-bay	Field	AD-60 D-Dot	430 pulsed	Rhombic	V	a/c nose incident	F
I3	EB3	E-bay	Cable Current	I-320 Probe	430 pulsed	Rhombic	V	a/c nose incident	F
I4	C1	Cabin	Field	AD-60 D-Dot	430 pulsed	Rhombic	V	a/c nose incident	F
I5	C2	Cabin	Wire Current	I-320 Probe	430 pulsed	Rhombic	V	a/c nose incident	F
I6	C3	Cabin	Voltage	Long Wire	430 pulsed	Rhombic	V	a/c nose incident	F
I7	C4	Cabin	Field	Ext. antenna	430 pulsed	Rhombic	V	a/c nose incident	C, F

• **Notes: This measurement set will investigate or validate:**
C) Calibration of aircraft external field measurement
F) On-board instrumentation check-out
F) Measure aircraft Q

Table C-20. Test Series J

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Config.	Notes
J1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	nose incident, AM	G
J2	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	nose incident, AM	G
J3	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	nose incident, AM	G
J4	CP4	Cockpit	Wire Current	I-320 Probe	0.3 - 1000	Rhombic	V	nose incident	H
J5	CP5	Cockpit	Wire Voltage	climbing wire	0.3 - 1000	Rhombic	V	nose incident	H
J6	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	small box	L
J7	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	small box	L
J8	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	small box	L
J9	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	move sensor box	L
J10	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	move sensor box	L
J11	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	move sensor box	L
J12	CP1	Cockpit	Vert. Field	AD-60 D-Dot	800 - 900	Rhombic	V	1% BW, 1000 pts	E
J13	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	person in left seat	M
J14	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	person in left seat	M
J15	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	person in left seat	M
J16	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	persons in both seats	M
J17	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	persons in both seats	M
J18	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	persons in both seats	M
J19	CP12	Cockpit	Heater Current	I-320 Probe	0.3 - 1000	Rhombic	V	new probe position	N
J20	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	repeatability, PM	K
J21	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	repeatability, PM	K
J22	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	repeatability, PM	K
J23	EB1	E-bay	Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	nose incident	G
J24	EB2	E-bay	LRU Voltage	Voltage Probe	0.3 - 1000	Rhombic	V	nose incident	J
J25	EB3	E-bay	Cable Current	I-320 Probe	0.3 - 1000	Rhombic	V	nose incident	H
J26	EB1	E-bay	Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	nose incident	G2
J27	EB2	E-bay	LRU Voltage	Voltage Probe	0.3 - 1000	Rhombic	V	nose incident	G2
J28	EB3	E-bay	Cable Current	I-320 Probe	0.3 - 1000	Rhombic	V	nose incident	G2
J29	EB1	E-bay	Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	nose incident	G3
J30	EB2	E-bay	LRU Voltage	Voltage Probe	0.3 - 1000	Rhombic	V	nose incident	G3
J31	EB3	E-bay	Cable Current	I-320 Probe	0.3 - 1000	Rhombic	V	nose incident	G3
J32	C1	Cabin	Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	nose incident	G
J33	C2	Cabin	Wire Current	I-320 Probe	0.3 - 1000	Rhombic	V	nose incident	H
J34	C3	Cabin	Voltage	Long Wire	0.3 - 1000	Rhombic	V	nose incident	H
J35	C4	Cabin	Field	Ext. antenna	0.3 - 1000	Rhombic	V	nose incident	I
J36	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	move a/c 10° off axis	P
J37	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	move a/c 10° off axis	P
J38	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	move a/c 10° off axis	P
J39	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	move a/c 5° off	P
J40	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	move a/c 5° off	P
J41	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	move a/c 5° off	P

• **Notes: This measurement set will investigate or validate:**

E) Variations in coupling with frequency (frequency stirring)
G) FDTD predictions of field coupling; plane wave incident
G2) E Bay hatch cover electrically sealed with conducting tape to assess leakage at seam
G3) E Bay hatch cover open to assess energy leakage
H) FDTD predictions of thin wire coupling; plane wave incident
I) Calibration of aircraft external field measurement, plane wave incident
J) Typical coupling into a representative critical LRU in the E-bay, plane wave incident
K) Repeatability
L) FDTD resolution element effects. "Small box" refers to emplacement of a small metallic box (dimensions order of resolution element size) near the sensor box. Movement of sensor box may be impossible if rigidly bonded to airframe
M) Stirring effects caused by people. Remove small box
N) Cockpit Window model
P) Angular sensitivity. Movement to 5° will be performed if measurements at 10° indicate strong sensitivity

Table C-21. Test Series K

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Config.	Notes
K1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	side incident	G
K2	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	side incident	G
K3	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	side incident	G
K4	CP4	Cockpit	Wire Current	I-320 Probe	0.3 - 1000	Rhombic	V	side incident	H
K5	CP5	Cockpit	Wire Voltage	climbing wire	0.3 - 1000	Rhombic	V	side incident	H
K6	EB1	E-bay	Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	side incident	G
K7	EB2	E-bay	LRU Voltage	Voltage Probe	0.3 - 1000	Rhombic	V	side incident	J
K8	EB3	E-bay	Cable Current	I-320 Probe	0.3 - 1000	Rhombic	V	side incident	H
K9	C1	Cabin	Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	side incident	G
K10	C2	Cabin	Wire Current	I-320 Probe	0.3 - 1000	Rhombic	V	side incident	H
K11	C3	Cabin	Voltage	Long Wire	0.3 - 1000	Rhombic	V	side incident	H
K12	C4	Cabin	Field	Ext. antenna	0.3 - 1000	Rhombic	V	side incident	I
K13	C3	Cabin	Voltage	Long Wire	0.3 - 1000	Rhombic	V	repeatability	K
K14	C3	Cabin	Voltage	Long Wire	0.3 - 1000	Rhombic	V	move bodies in cabin	M
K15	EB3	E-bay	Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	repeatability	K
K16	CP1	Cockpit	Vert. Field	AD-60 D-Dot	800 - 900	Rhombic	V	1% BW, 1000 pts	E
K17	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	person in left seat	M
K18	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	person in left seat	M
K19	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	person in left seat	M
K20	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	persons in both seats	M
K21	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	persons in both seats	M
K22	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	persons in both seats	M
K23	CP5	Cockpit	Wire Voltage	climbing wire	0.3 - 1000	Rhombic	V	add parasitic wire	O
K24	CP5	Cockpit	Wire Voltage	climbing wire	0.3 - 1000	Rhombic	V	add parasitic wire	O
K25	CP12	Cockpit	Heater current	I-320 Probe	0.3 - 1000	Rhombic	V	new probe position	N
K26	C3	Cabin	Voltage	Long Wire	0.3 - 1000	Rhombic	V	add static ground	Q
K27	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	return to nose incident	R
K28	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	return to nose incident	R
K29	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	return to nose incident	R

• **Notes: This measurement set will investigate or validate:**

E) Variations in cowpling with frequency (frequency stirring)
G) FDTD predictions of field coupling; plane wave incident
H) FDTD predictions of thin wire coupling; plane wave incident
I) Calibration of aircraft external field measurement, plane wave incident
J) Typical coupling into a repsesentative critical LRU in the E-bay, plane wave incident
K) Repeatability (instrumentation)
M) Stirring effects caused by people. Remove small box
O) Effect of cable loads on cavity absorption
P) Angular sensitivity
Q) Effect of ground wire
R) Repeatability (angular)

 Skip if included in previous test series

Table C-22. Test Series PL

TX Ant location	Rx Ant location	Comments
A) STATISTICAL CHARACTERIZATION/INSERTION LOSS		
#1	four locations in cockpit	
#2	four locations in cockpit	
#3	four locations in electronics bay	
#4	four locations in cabin	
#5	four locations in cabin	
B) CAVITY Q		
#1	one location in cockpit	use DSA 602, 100 MHz steps to 1 GHz, 200 MHz steps from 1 GHz to 6 GHz
#3	one location in electronics bay	use DSA 602, 100 MHz steps to 1 GHz, 200 MHz steps from 1 GHz to 6 GHz
#4	one location in cabin	use DSA 602, 100 MHz steps to 1 GHz, 200 MHz steps from 1 GHz to 6 GHz
C) CAVITY TO CAVITY COUPLING		
#1	four locations in cabin	
#1	four locations in electronics bay	
#3	four locations in cockpit	
#3	four locations in cabin	
#4	four locations in cockpit	
#4	four locations in electronics bay	

Table C-23. Test Series Pad Characterization

Measurement	Probe	Frequencies Range	Frequencies Increment	Positions
Case 1 and Case 2				
Current	Prodyn I-320	1 to 13 MHz 110 to 1000 MHz	2 MHz 10 MHz	Pairs: Starting 22.5 m from feed $P_n = \{22.5 + \Delta r\,(2n-2),\ 22.5 + \Delta r\,(2n-1)\}$ for n=1 to 45 with Δr = 30 cm

Table C-24. Horizontal Polarization - Rhombic

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Config.	Notes
HP1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	3 - 30	Rhombic	H	Side incident	A
HP2	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	3 - 30	Rhombic	H	Side incident	A
HP3	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	3 - 30	Rhombic	H	Side incident	A
HP4	CP4	Cockpit	Wire Current	I-320 Probe	3 - 30	Rhombic	H	Side incident	B
HP5	CP5	Cockpit	Wire Voltage	climbing wire	3 - 30	Rhombic	H	Side incident	B
HP6	EB1	E-bay	Field	AD-60 D-Dot	3 - 30	Rhombic	H	Side incident	A
HP7	EB2	E-bay	LRU Voltage	Voltage Probe	3 - 30	Rhombic	H	Side incident	D
HP8	EB3	E-bay	Cable Current	I-320 Probe	3 - 30	Rhombic	H	Side incident	B
HP9	C1	Cabin	Field	AD-60 D-Dot	3 - 30	Rhombic	H	Side incident	A
HP10	C2	Cabin	Wire Current	I-320 Probe	3 - 30	Rhombic	H	Side incident	B
HP11	C3	Cabin	Voltage	Long Wire	3 - 30	Rhombic	H	Side incident	B
HP12	C4	Cabin	Field	Ext. antenna	3 - 30	Rhombic	H	Side incident *	C
HP13	Weak Signal Line				3 - 30	Rhombic	H	Side incident	V
HP14	Strong Signal Line				3 - 30	Rhombic	H	Side incident	V

• **Notes: This measurement set will investigate or validate:**

A) FDTD predictions of field coupling
B) FDTD predictions of thin wire coupling
C) Calibration of aircraft external field measurement
D) Typical coupling into a representative critical LRU in the E-bay
V) Dipole Instrumentation Noise Measurements
* Lower priority, skip if short of time

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